EMCal simulation Summary and Plan

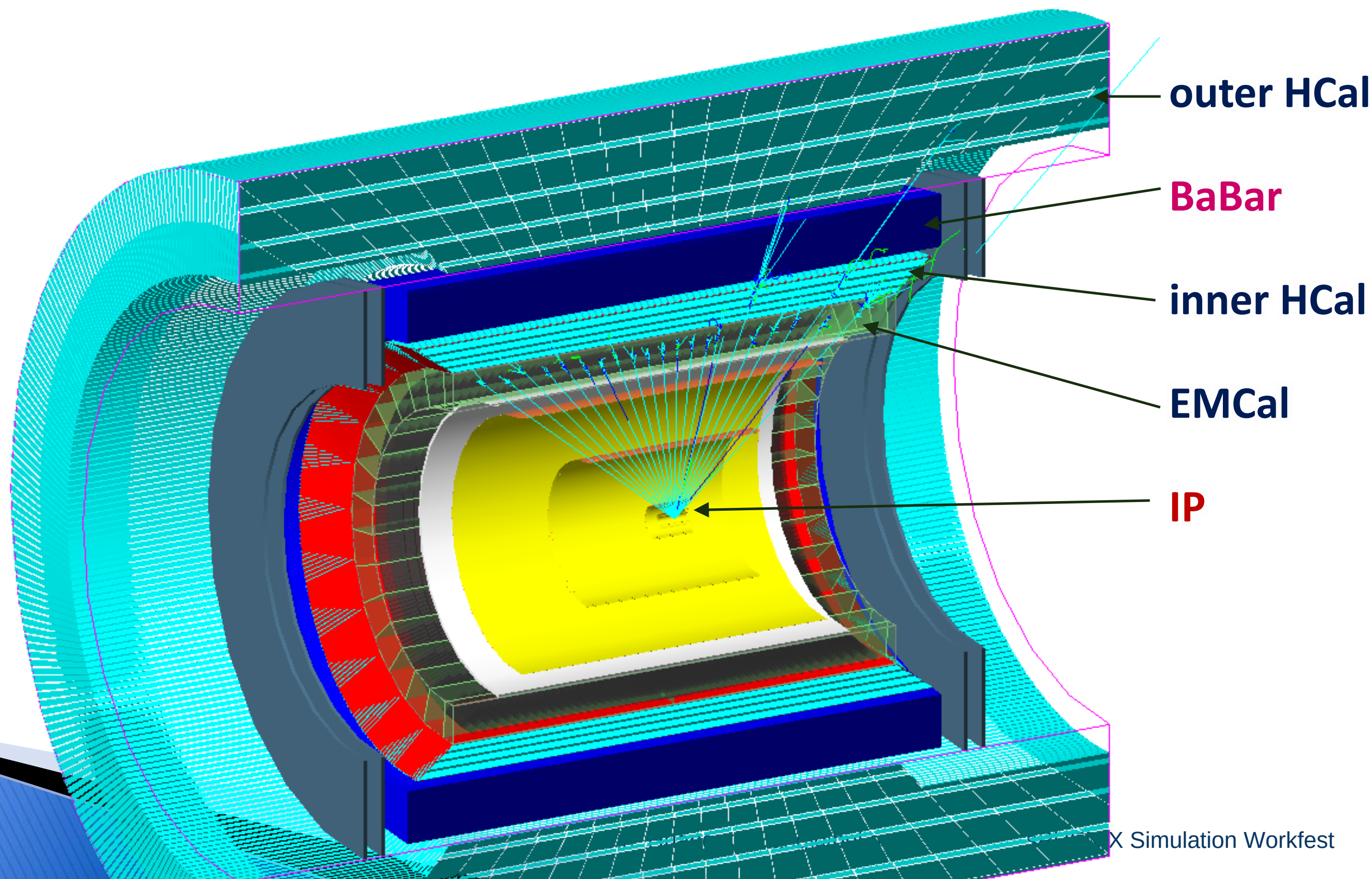
Outline: sPHENIX EMCal Overview • Projective design update • Other simulation tasks

Jin Huang (BNL)

Brief summary for proposal simulation studies

sPHENIX Calorimeters

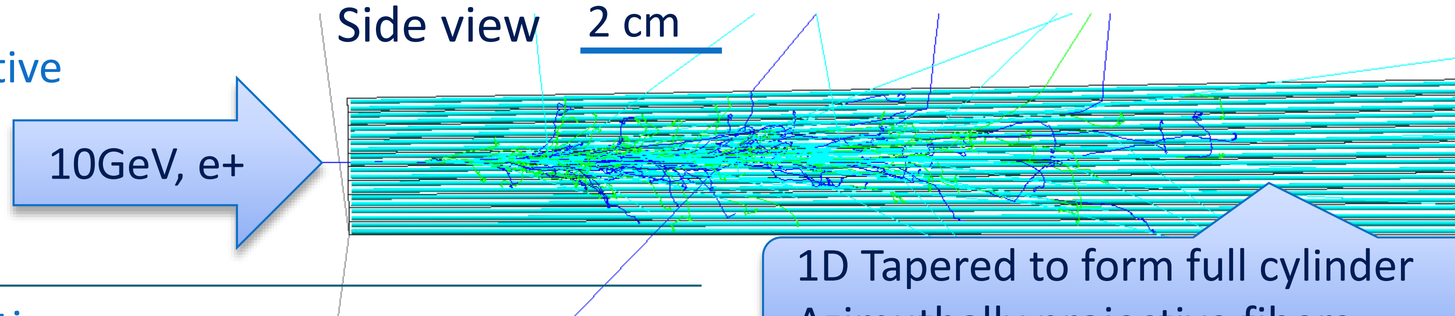
- EM calorimeter (EMCal) : 18 X_0 SPACAL
- Inner hadron calorimeter (inner HCal) : 1 λ_0 SS-Scint. sampling
- BaBar coil and cryostat. (BaBar): 1 X_0
- Outer hadron calorimeter (outer HCal) : 4 λ_0 SS-Scint. sampling



SPACAL module simulation

- SPACAL implemented in sPHENIX simulation framework
  - Thanks to reference model from A. Kiselev (EIC taskforce & EIC RD1)
- 10 GeV electron shower in a single SPACAL module shown
- Covered full azimuthal and $|\eta|<1.1$ in sPHENIX
- Default: 1-D projective in azimuth. Available for test: full projective

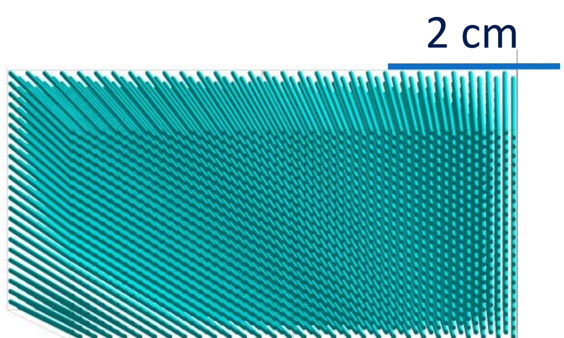
1-D projective



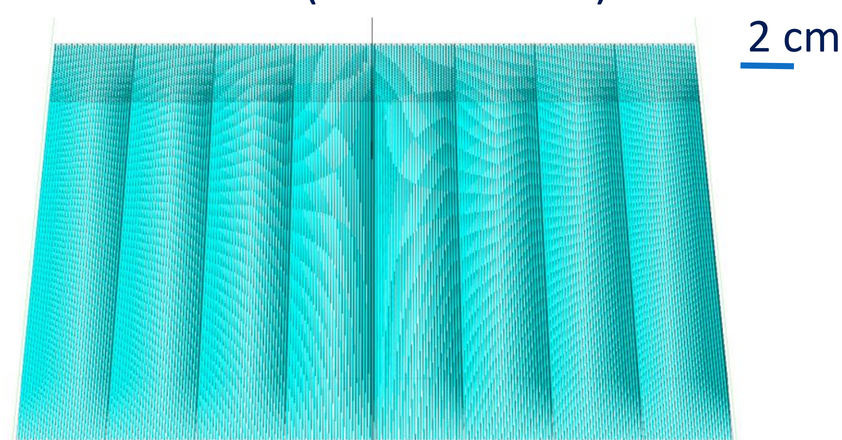
1D Tapered to form full cylinder
Azimuthally projective fibers

Full projective

Particle view (2x1 modules)



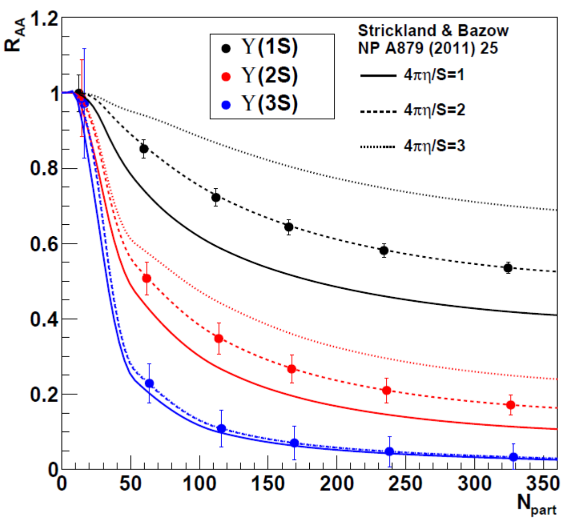
Side view (8x1 modules)



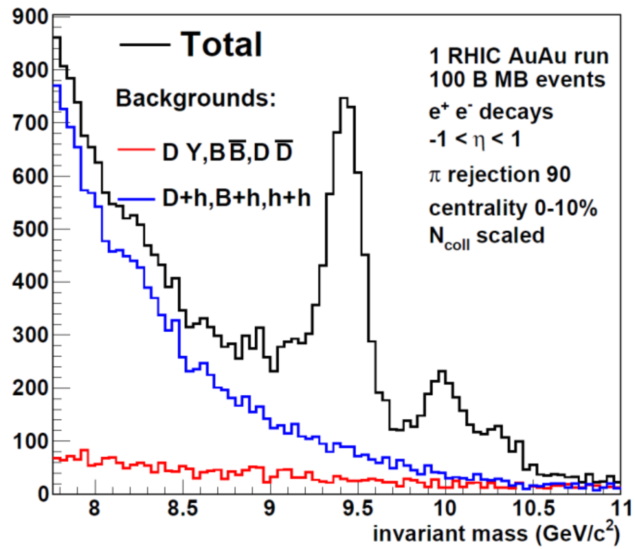
sPHENIX EMCal

1. Upsilon electron ID – main driving factor
2. Direct photon ID
3. Heavy flavor electron ID
4. Part of jet energy determination

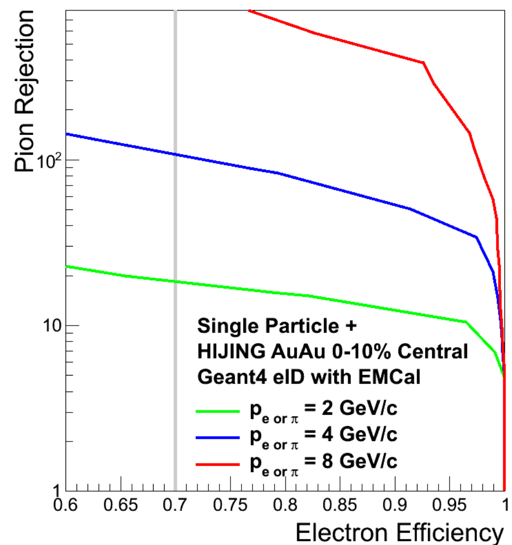
Upsilon R_{AA}



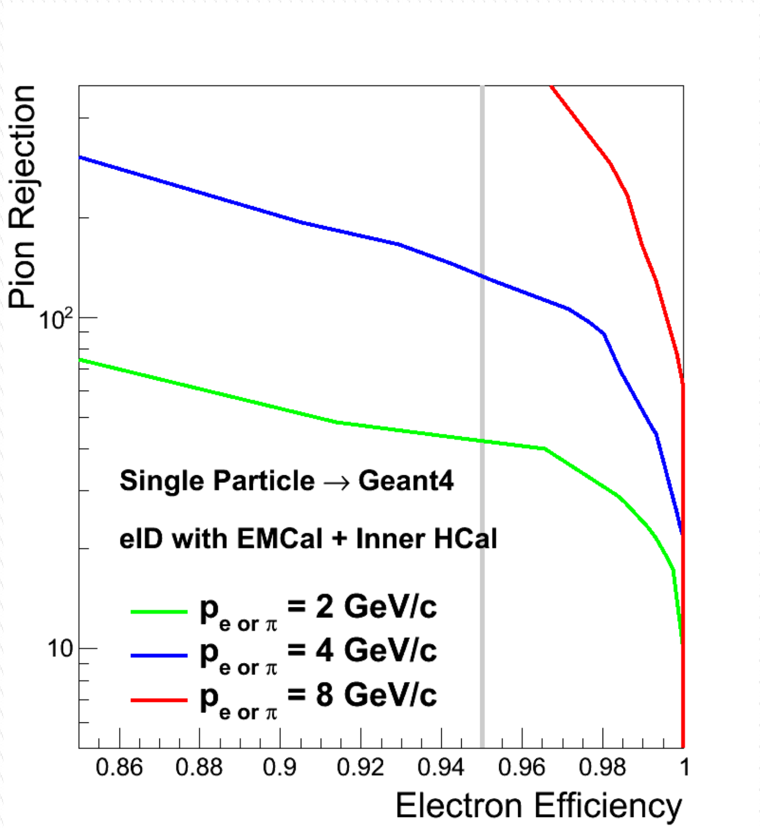
Hadron VS Upsilon

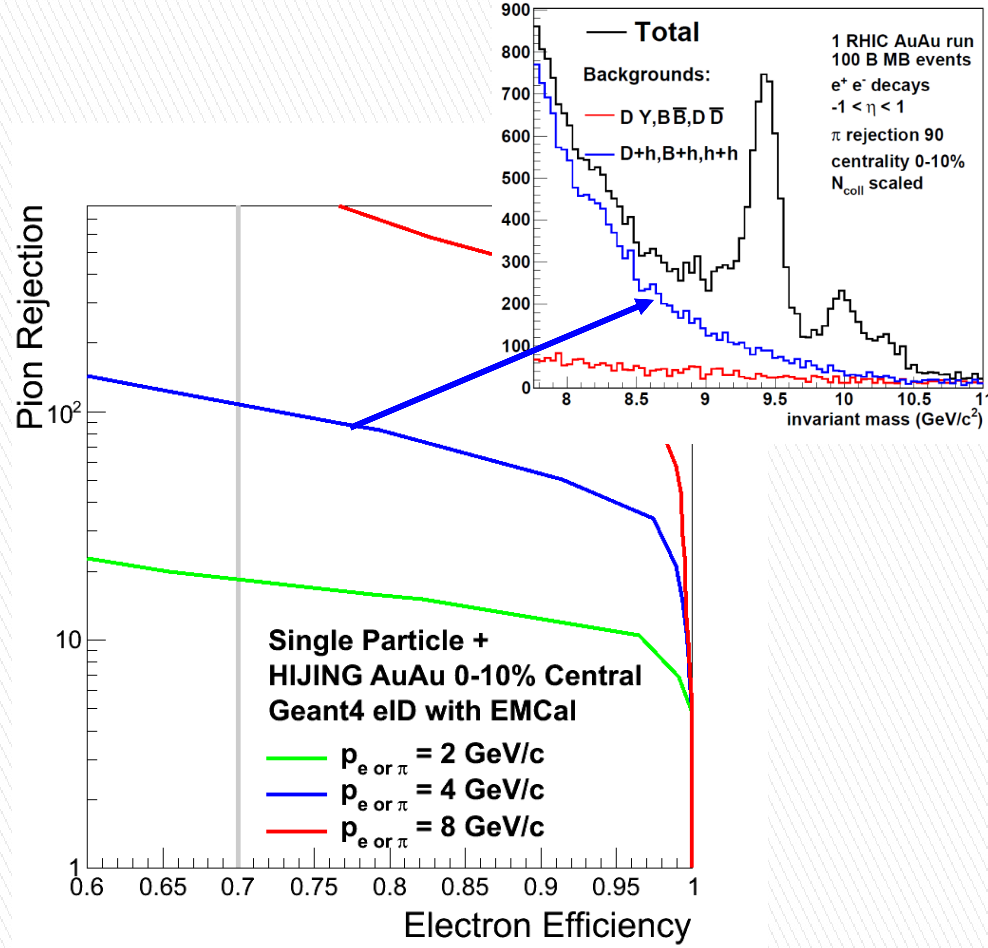


Hadron Rej. ~100:1



Compile everything together for barrel electron ID

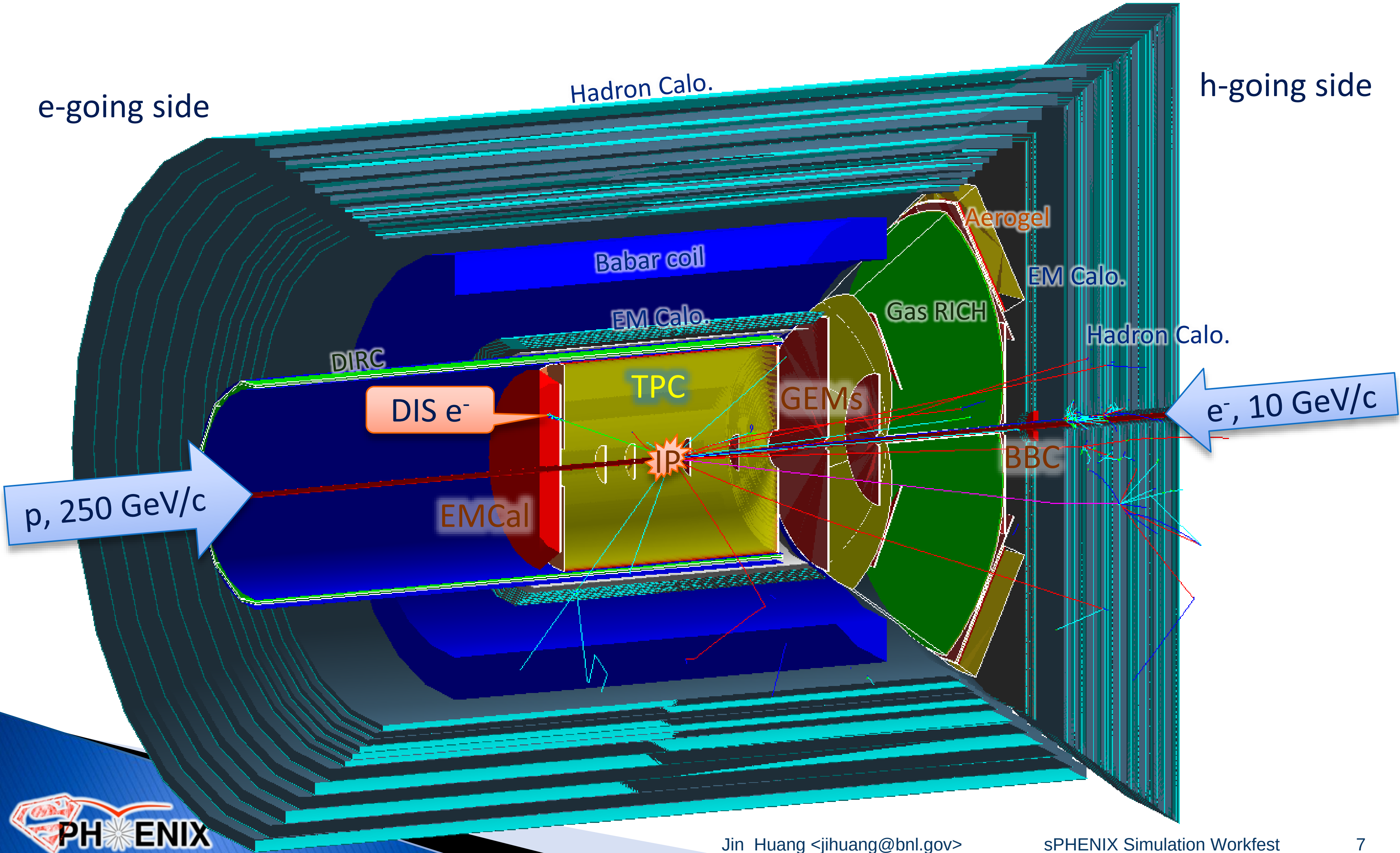




pp/ep electron ID (EMC+HCAL)

Central AA electron ID (EMC Only)

Calorimeters in e/fsPHENIX

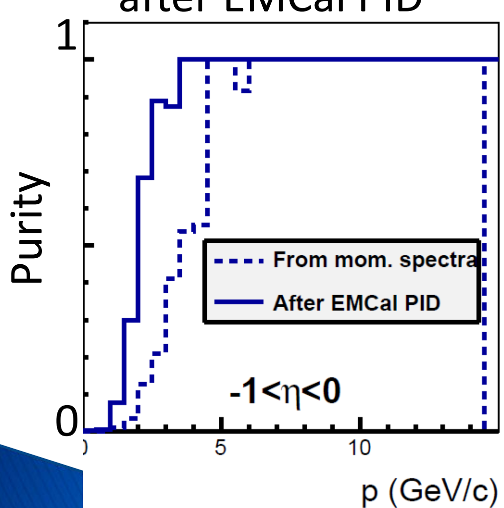


Use of calorimeter for EIC physics

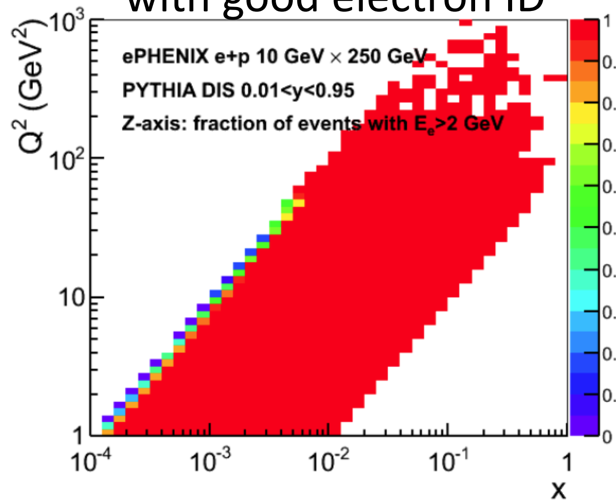
- Electron identification (e-EMC, barrel EMC)
- Electron kinematics measurement (e-EMC, barrel EMC)
- DIS kinematics using hadron final states (barrel EMC/HCal, h-EMC/HCal)
- Photon ID for DVCS (All EMC)

From Sasha and Karen using parameterized performance

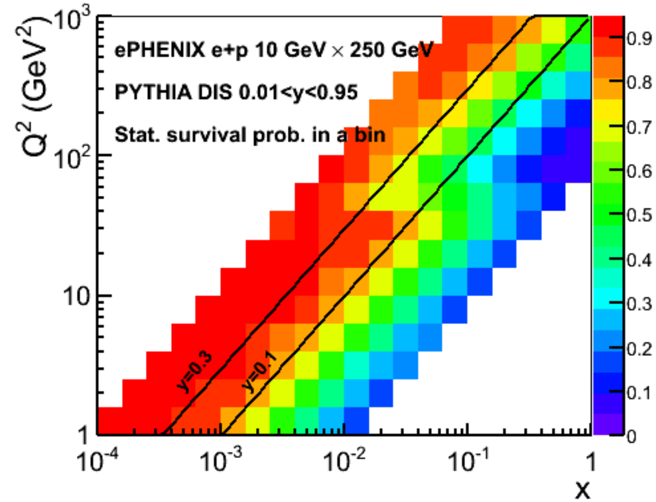
Electron purity after EMCal PID



Fraction of DIS event with good electron ID



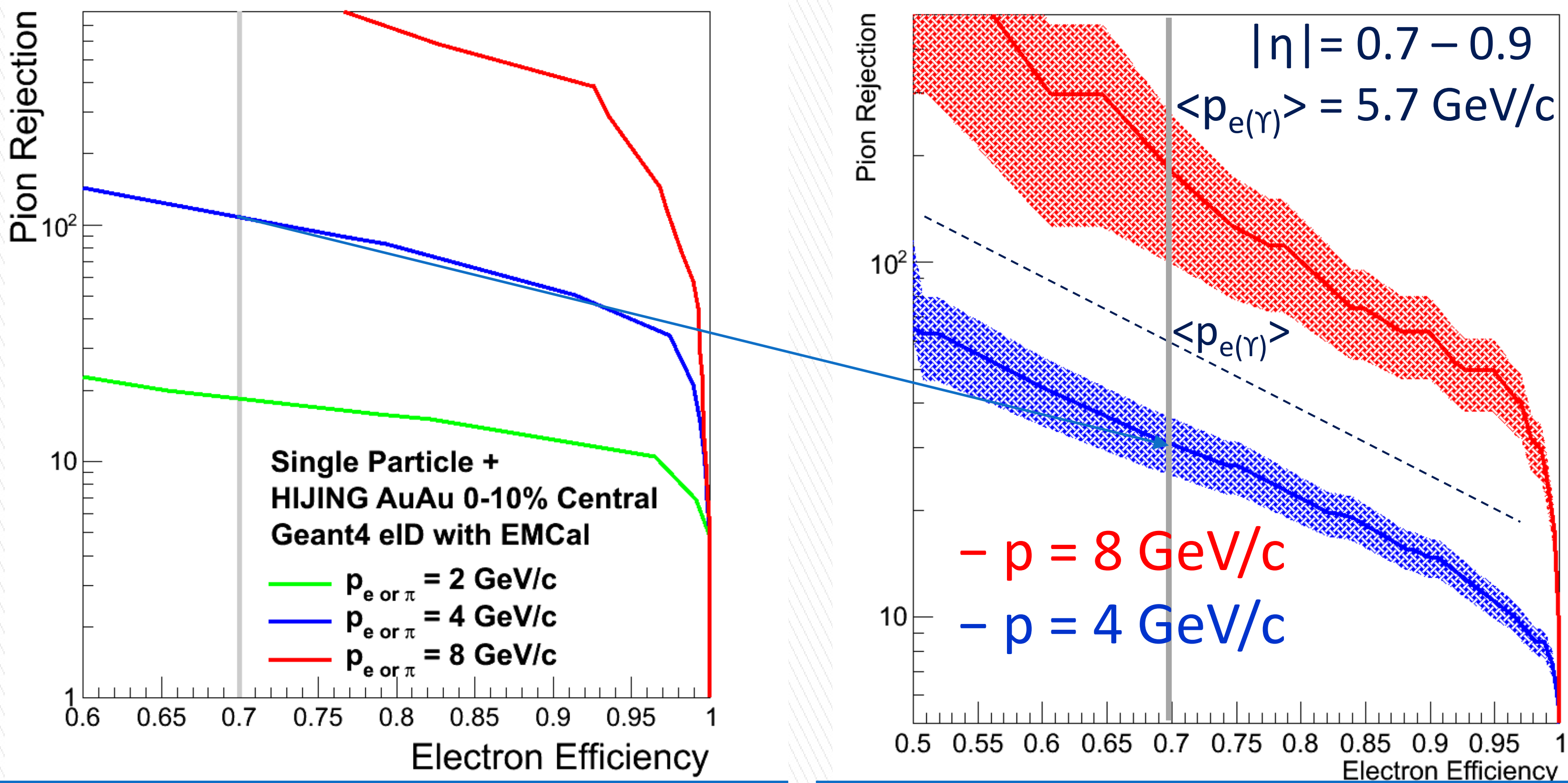
DIS kinematics survivability Electron kinematic method



Recent progress on Projective EMCal design

- Needs for 2D tapered SPACAL
- R&D progress
- Simulation implementation: New available for test from GitHub

Quantitative comparison for EID performance in Geant4 (group hits to simulate for towers)



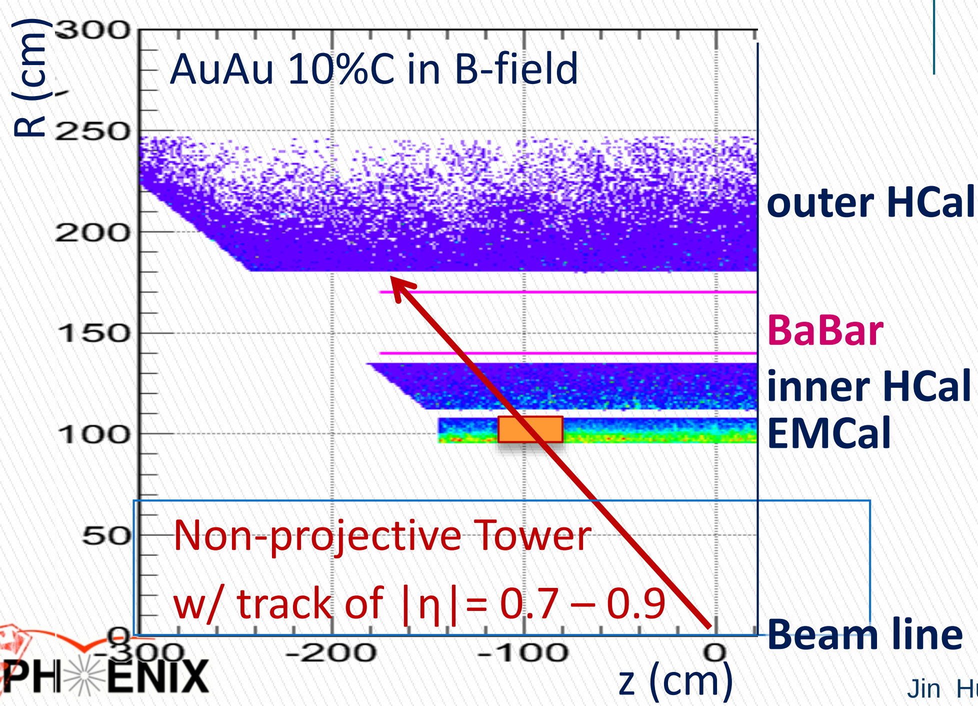
Central rapidity, $|\eta| < 0.2$
Effectively projective in polar direction

Forward rapidity, $|\eta| = 0.7 – 0.9$
non-projective in polar direction

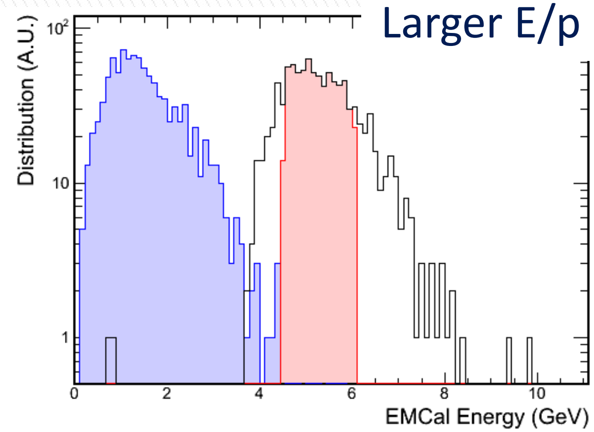
Larger pseudo-rapidity in central AuAu : under study

- Out of the box: larger |η| → larger background
  - Longer path length in calorimeter
  - Covers more non-projective towers
- to improve
  - **Better estimate of the underlying background event-by-event (improve x1.5)**
  - **Use (radially) thinner ECal (improve x2)**
  - **Possibilities for projective towers?**

- all events (w/ embedding)
- with EMCal E/p cut (w/ embedding)
- Hijing background (AuAu 10%C in B-field)

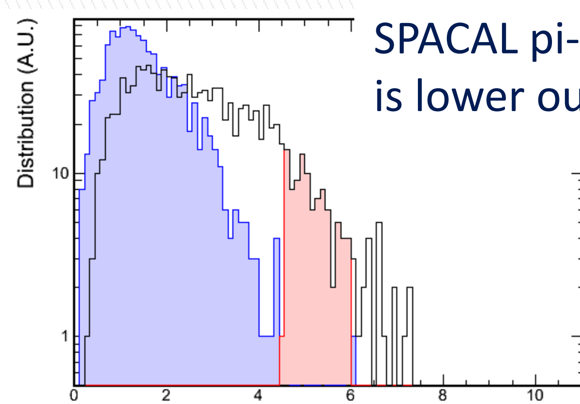


SPACAL e-
Larger E/p cuts



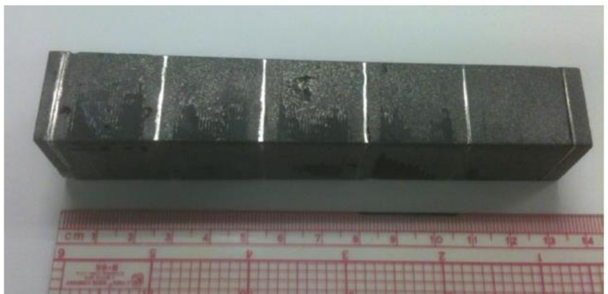
Out of box rejection ~10:1

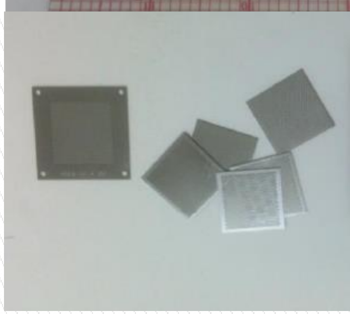
SPACAL pi- rejection
is lower out of the box

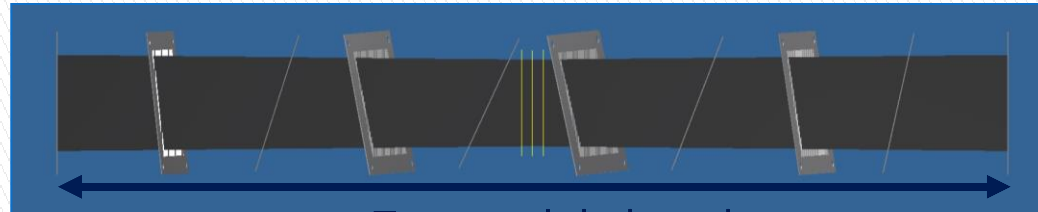


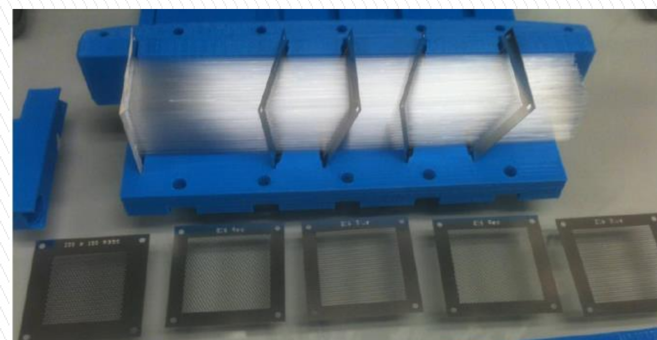
On-going R&D on 2D projective SPACAL

Sean Stoll (BNL), Spencer Locks (SBU), Jin Huang (BNL) and others







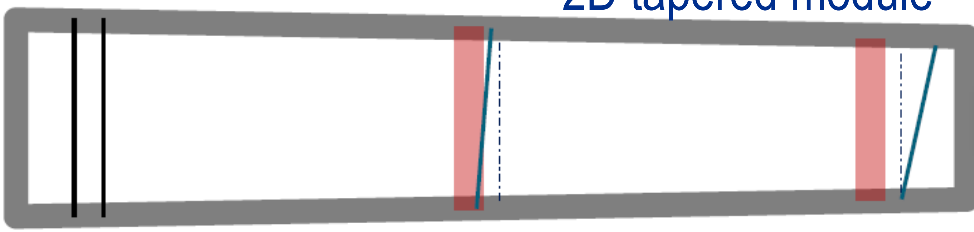


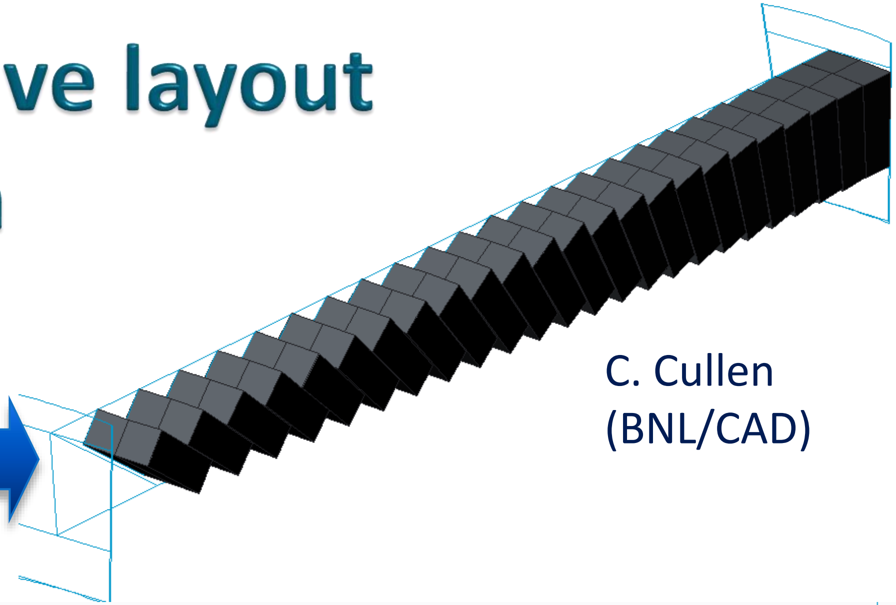
R&D Direction 1:
Tapered step screens

R&D Direction 2:
Tilting Wireframes

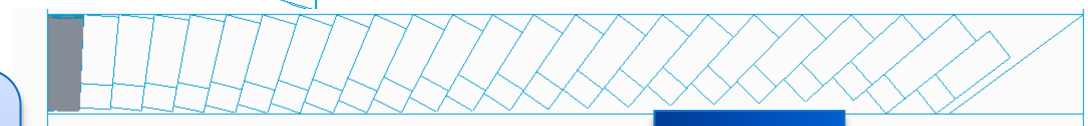
On-going: 2-D projective layout in CAD and simulation

2D tapered module



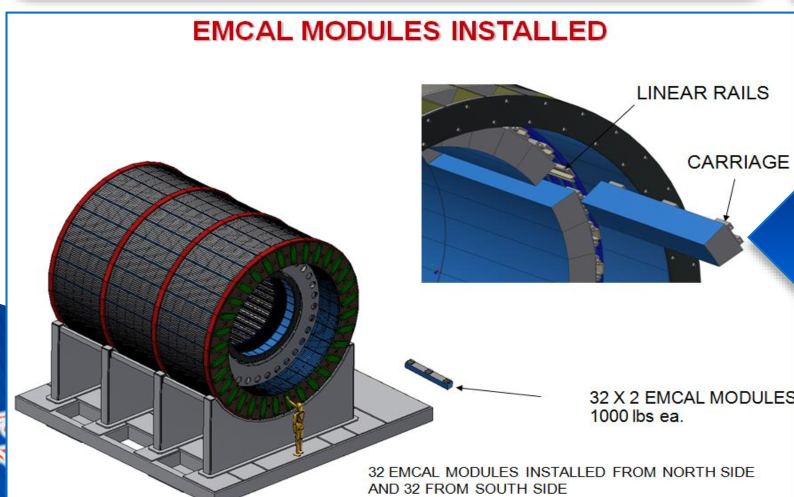


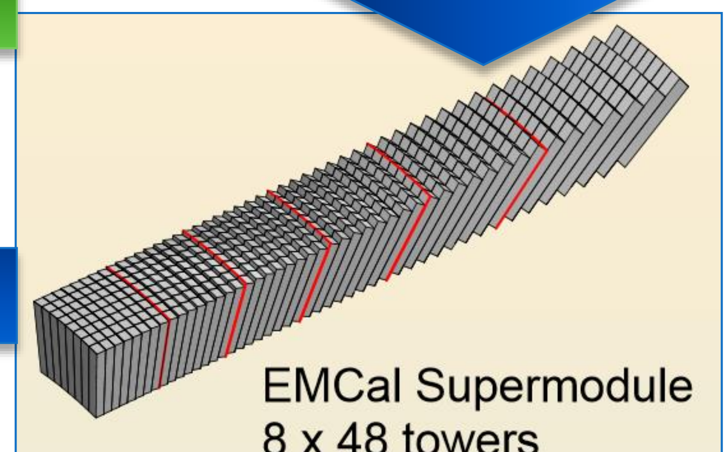
C. Cullen (BNL/CAD)



Simulation for 2-D projective EMCal: Plan to import the CAD geometry into sPHENIX Geant4

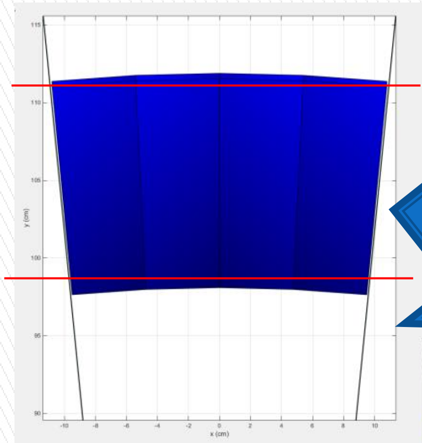
New



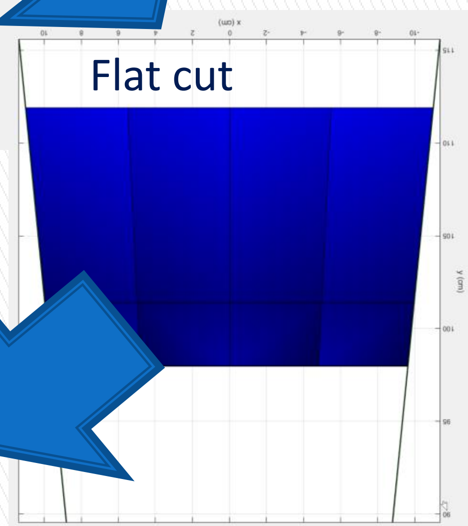


(Not yet updated to 2x2 block)

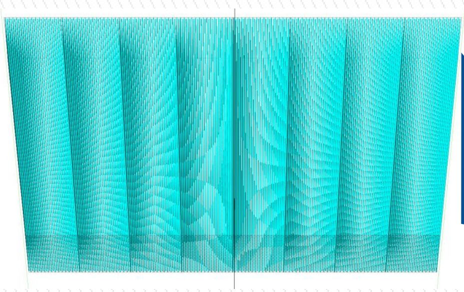
Further design and updates



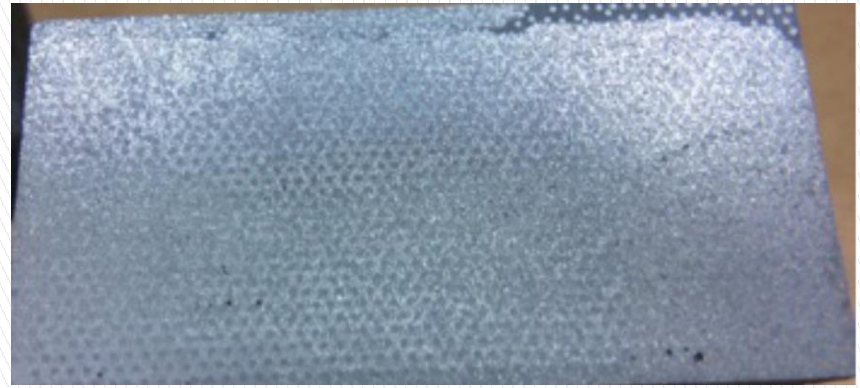
Original design

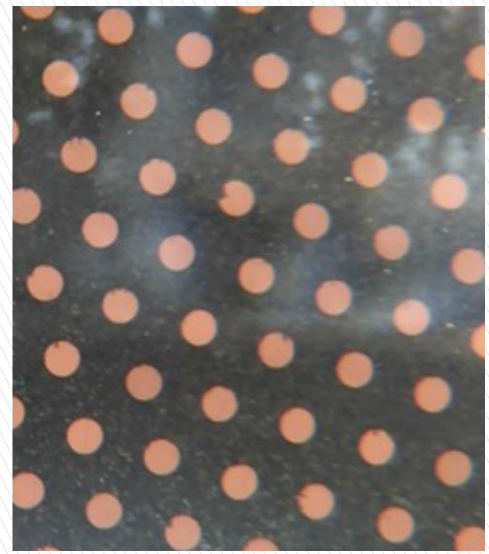


Geant4 with fiber



Build blocks to fit and machine cut top and bottom to flat

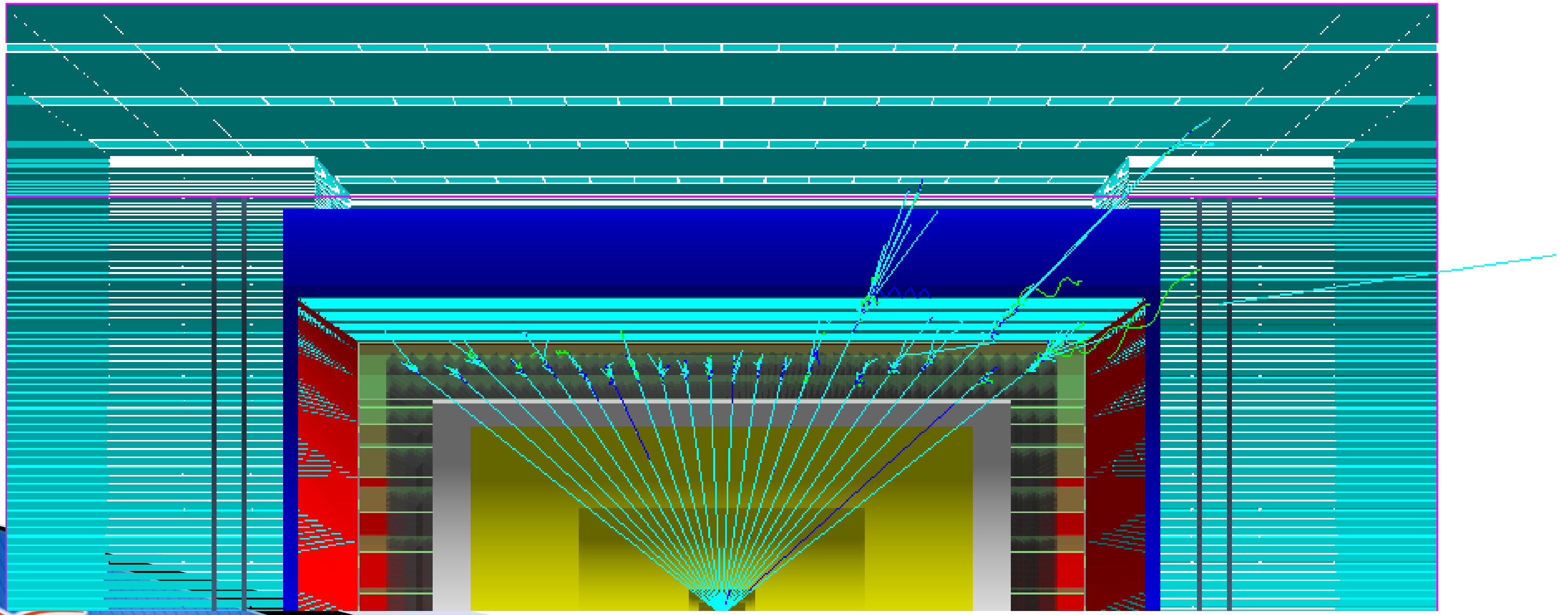


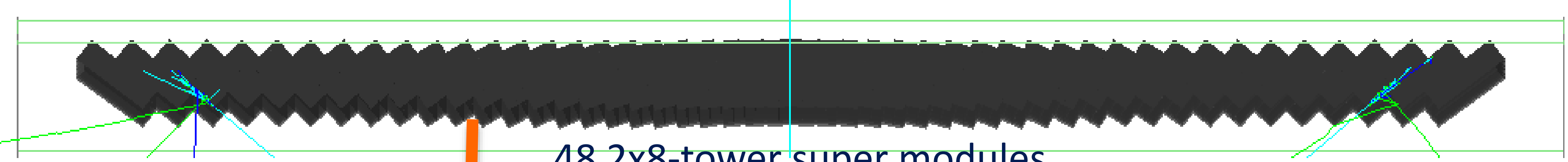


Experimental diamond cut UIUC group

Implementation in Geant4

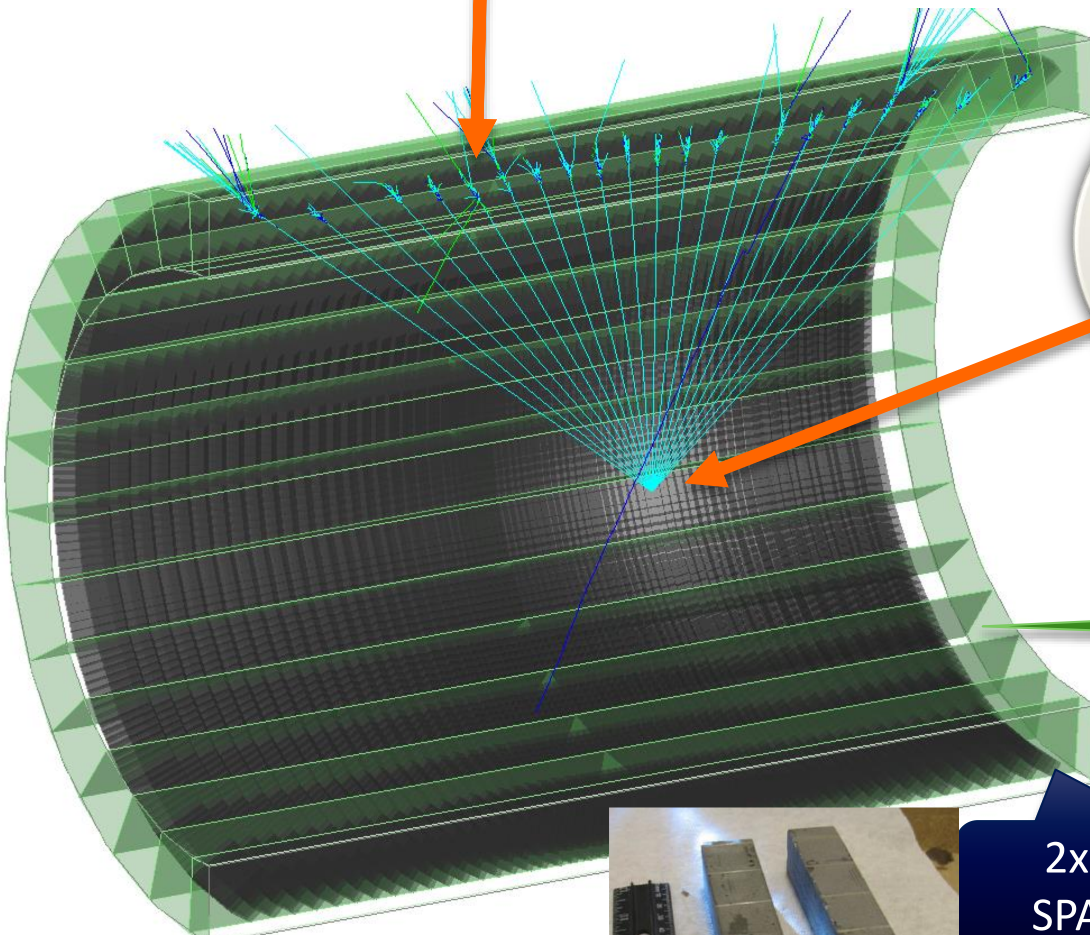
- Enabled with new branch 2DSpacal:
  - Not in nightly build by default (currently in evaluation)
  - To use: check out from GitHub:
    - https://github.com/sPHENIX-Collaboration/coresoftware/tree/2DSpacal
    - https://github.com/sPHENIX-Collaboration/macros/tree/2DSpacal
- Currently need ~5min to run the first event due to large number of unique geometry objects. Then ~2 EM shower/min

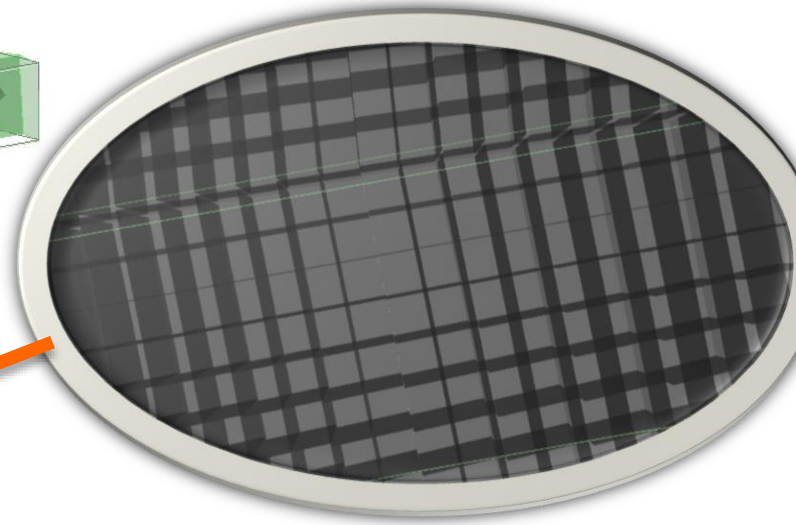




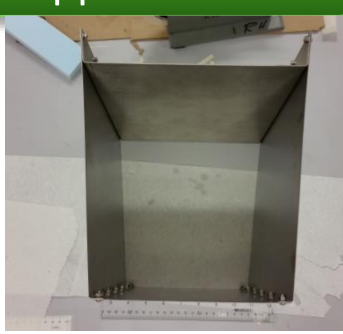
48 2x8-tower super modules

Towers project towards IP





Stainless steel SS310
Support box



2x2 2D tapered
SPACAL modules

Other simulation tasks

- Energy leakage
- Sampling fraction variation
- Detection response model
- Shower shape analysis

Details in Geant4 parameter tuning for fine-sampling calorimeter

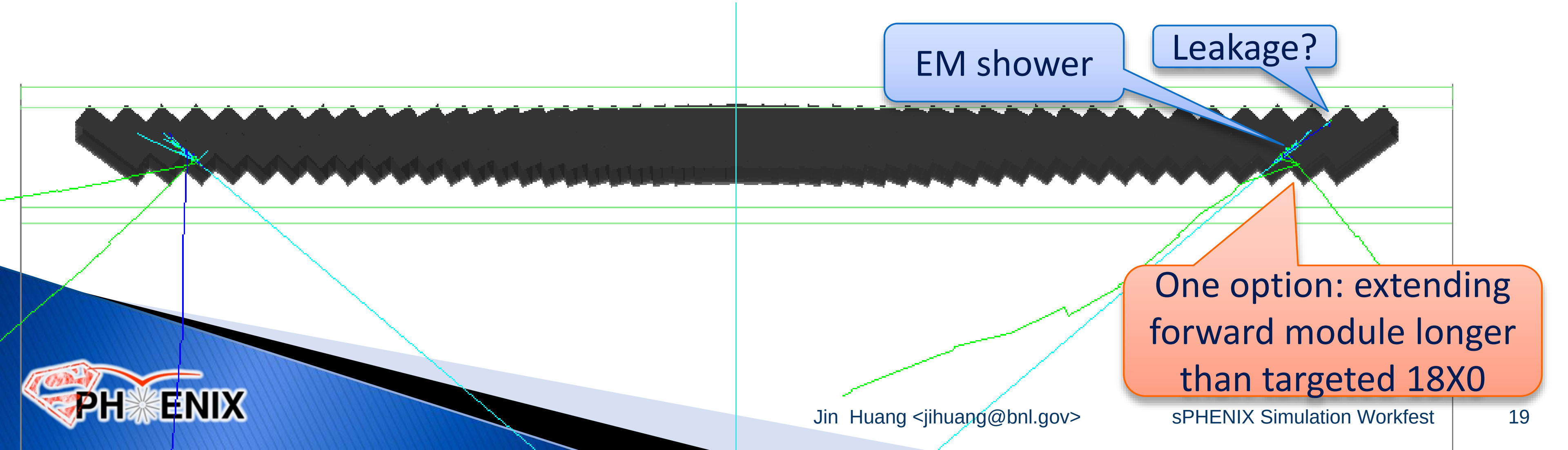
- In most current simulation of sPHENIX calorimeters, energy from calorimeter is sum of total energy deposition or ionization energy deposition
- In post-CD0-stage, more realistic simulations, several experimental factors need to be considered, including ionizing energy loss, scintillating light modeling, transportation of photons, and noise in SiPM
- Scintillating light modeling ready for CVS submission: scintillation light saturation modeling [Birk, Phys. Rev. 84, 364, 1951]
- Model parameters to verify: step size, final range and production threshold.
  - Eliton Popovicz (Baruch College) started the effort systematically verifying these parameters.
  - Need hadron/electron data to finalize the tune.

$$Light\ Yield \propto \frac{\frac{dE}{dx}}{1 + kB\,\frac{dE}{dx}}$$

k_B~ 0.07943*mm/MeV [Hirschberg, 1992]
0.126 mm/MeV [arXiv:1106.5649v2]

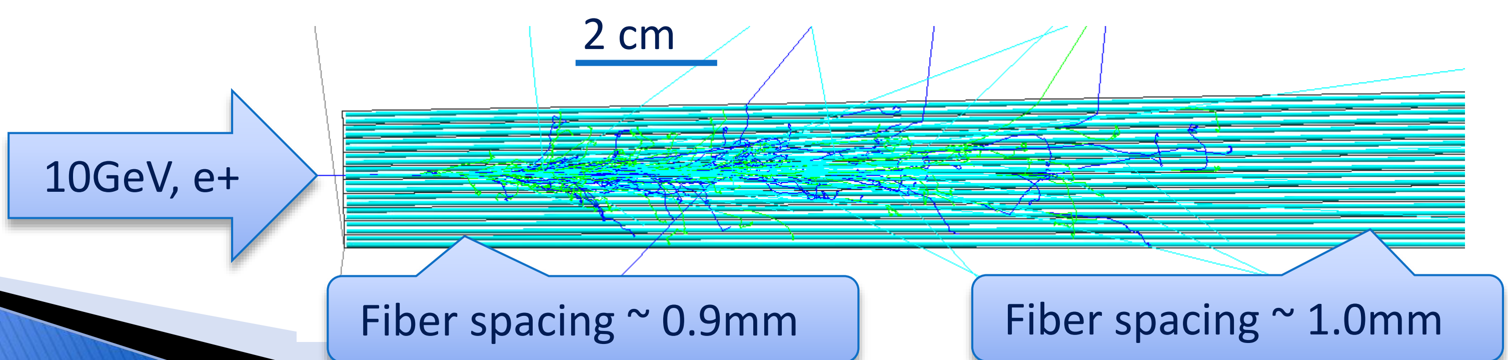
Rear leakage

- As in many block calorimeter, steps formed by staging blocks leads to position dependent rear leakage
- Already observed in 1x1 block during Martin's simulation by scanning response along z
- Remedy?
  - Use 1x1 module towards larger eta region, with higher production complexity
  - Make the forward module longer, so the overlap region remain the nominal ~18 X0
- Need to quantify this effect and remedies in Geant4
  Volunteer welcomed!



Sampling fraction variation

- In the current design 2D tapering in SPACAL comes with the cost that fiber density changes from front to back side of the SPACAL module by 10-20%
- This leads to a larger constant term in energy resolution
- Is this important comparing to 12%/sqrt(E) statistical term of energy resolution?
- Need to evaluate for both sPHENIX (eID performance, direct -Gamma) and EIC case (eID performance, kinematic smearing)
- Volunteer welcomed



Tower-by-tower shower shape analysis

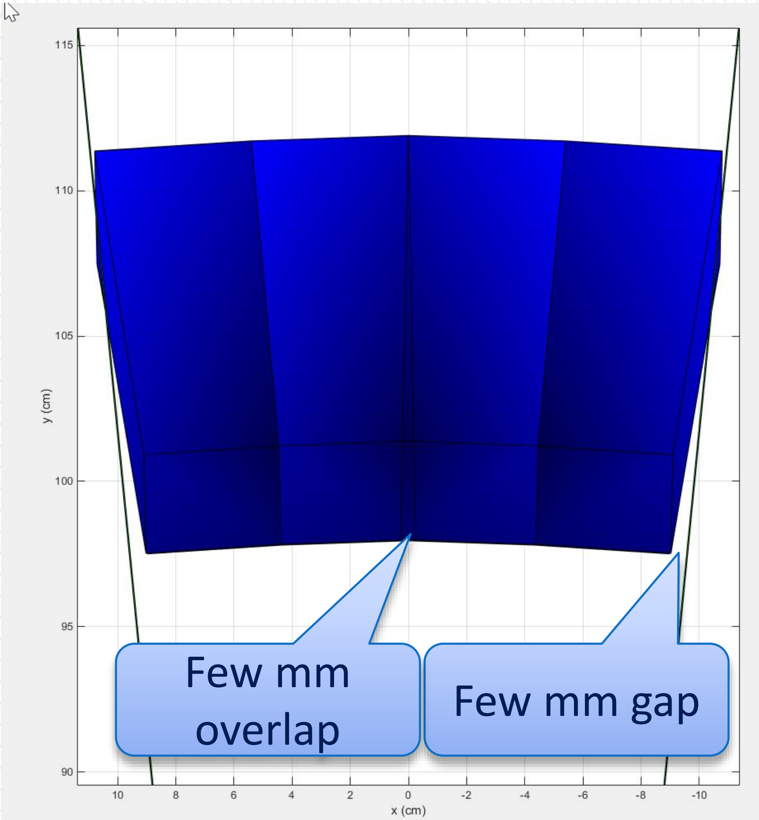
- Hadron shower extend larger than EM Shower, which provide additional handle on electron ID
- Track based cluster finding to fully use the information
- Exploring modern machine learning algorithm (e.g. Boosted decision tree or support vector machine) to evaluate PID based tower response around primary track
- How does it work in heavy ion environment?
- Volunteer welcomed

Summary

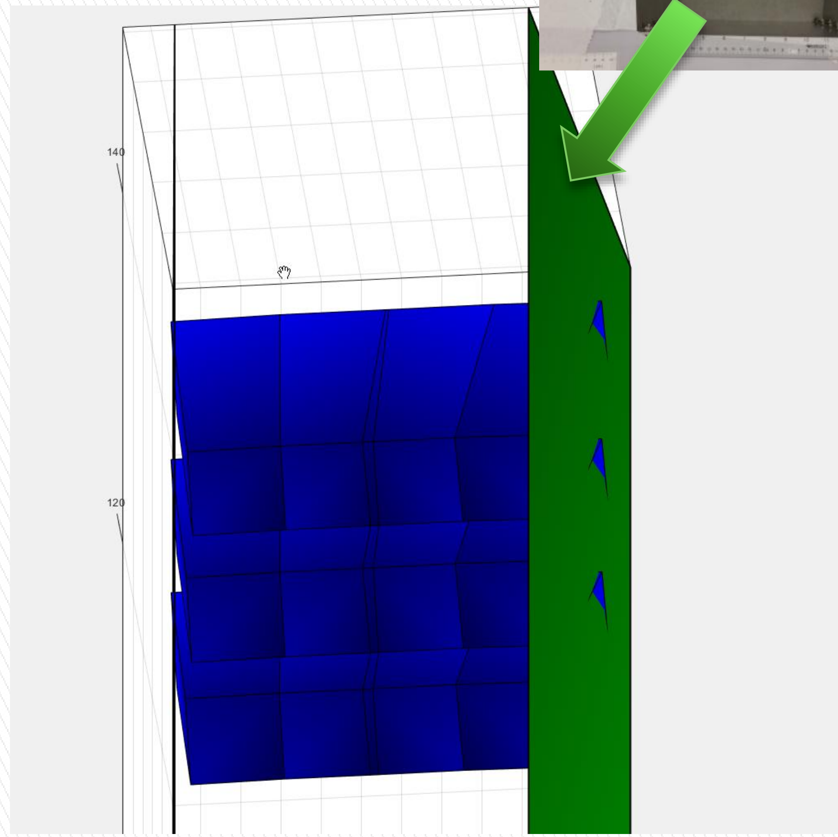
- On-going R&D on projectivity
  - On-going R&D make it more hopeful to construct 2-D projective EMCal to improve key eID performance in forward rapidity
- Imported and improved CAD layout to Geant4, now we can start to quantify the 2-D projective EMCal in sPHENIX
- Multiple TODO tasks welcome volunteers

Extra Information

However, right now there is a confliction and a gap

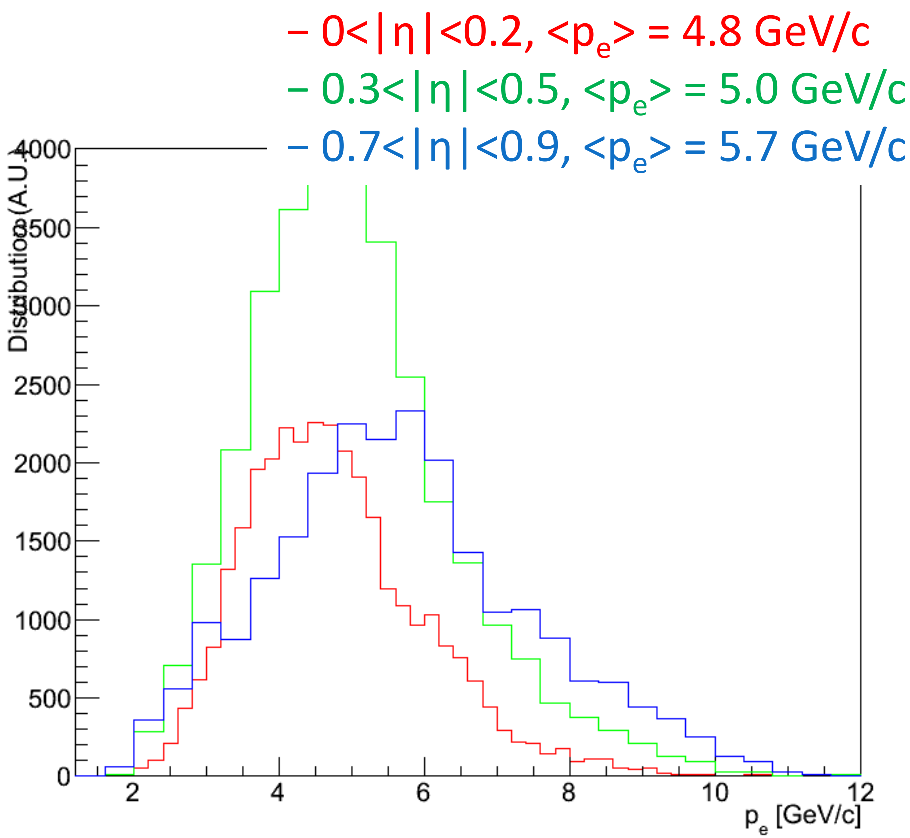


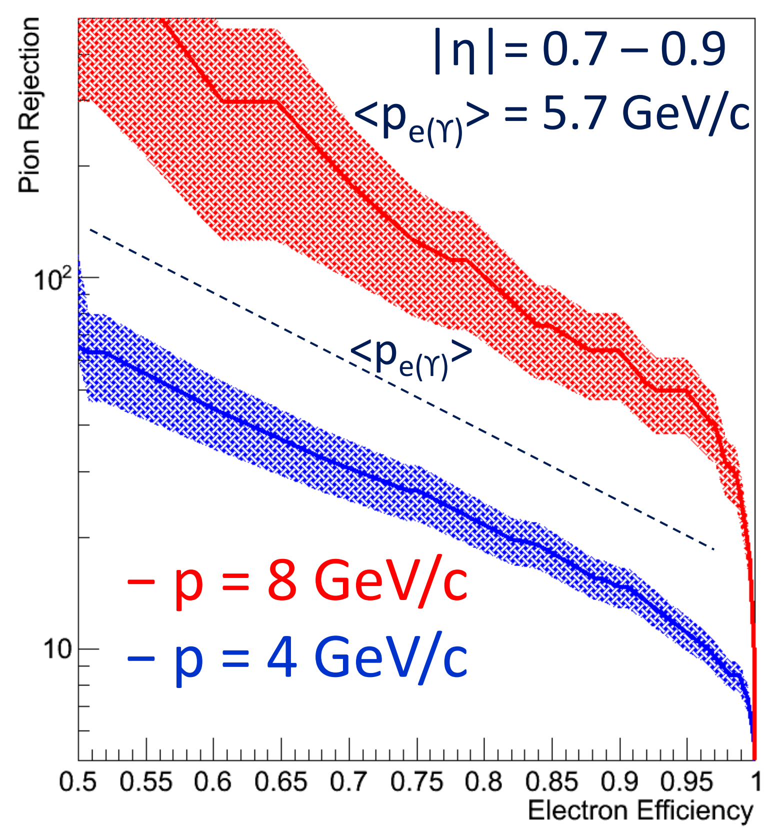
View of the last row of calorimeter long z axis



View of the last 3 rows of calorimeter from beam side

Momentum distribution of Upsilon Electrons, With thinner SPACAL + background sub. + NON-PROJECTIVE



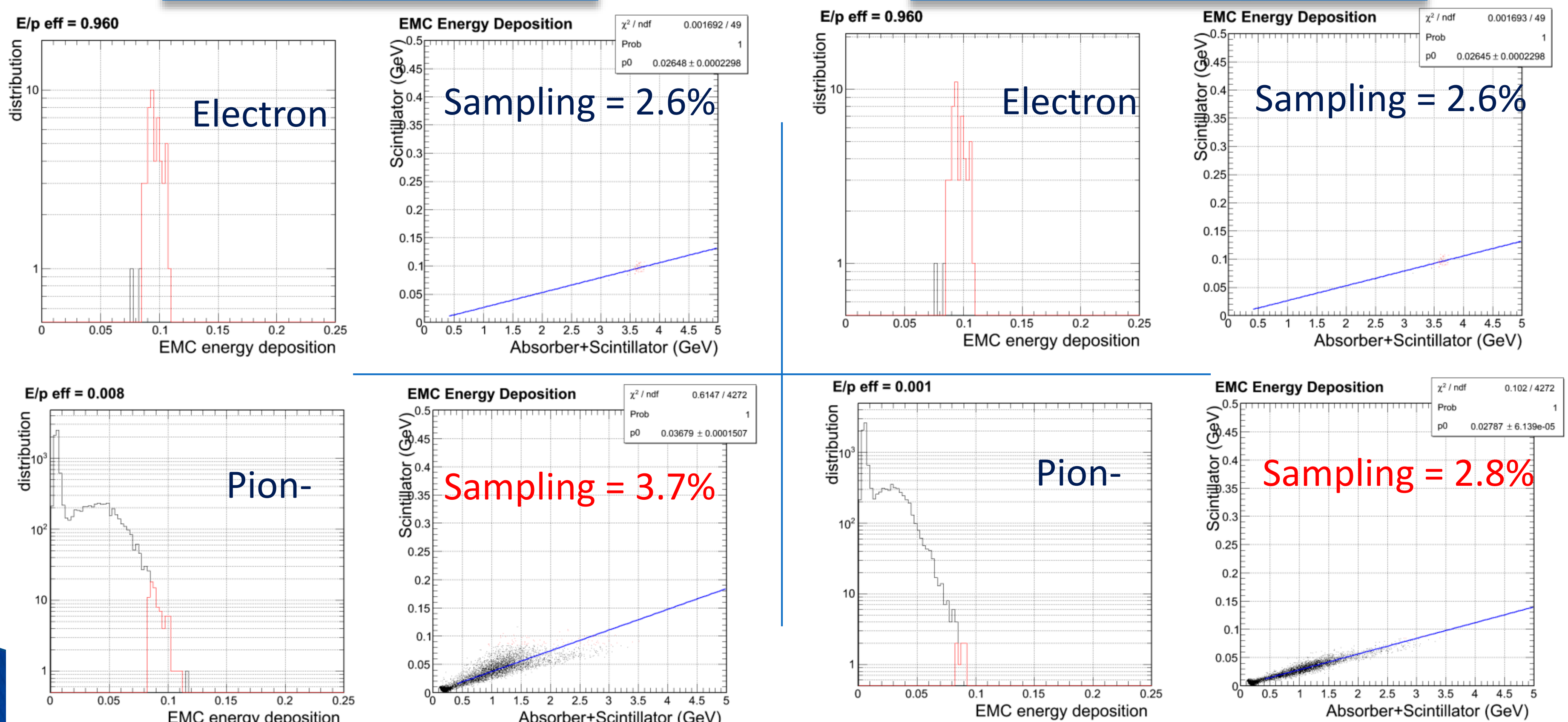


Implementing Birk's law

- Available now in G4hit level
- Could significantly affect e/h for both EMC and HCal

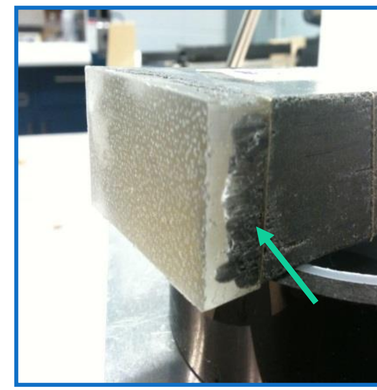
Sum energy deposition

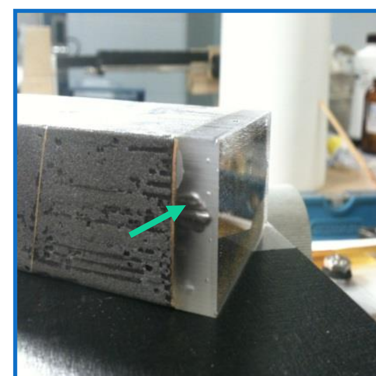
With scintillation light model



SPACAL module production at BNL

- We have produced 4 modules at BNL so far
- We are holding off on producing more until the new 2D taper meshes/screens come in, possibly this week
- We have sufficient fiber, tungsten powder, screens, epoxy to produce another 12 modules
- We feel that we have worked through most of the issues and understand the process well
- Some issues that we have dealt with:
  - air bubbles/tungsten powder inclusions in clear epoxy region
  - Full and uniform penetration of epoxy through the tungsten powder
  - Uniform surface characteristics
  - Uniform fiber distribution
  - End surface finish/polish
- One module is currently in the PHENIX IR as part of the SiPM radiation damage testing.



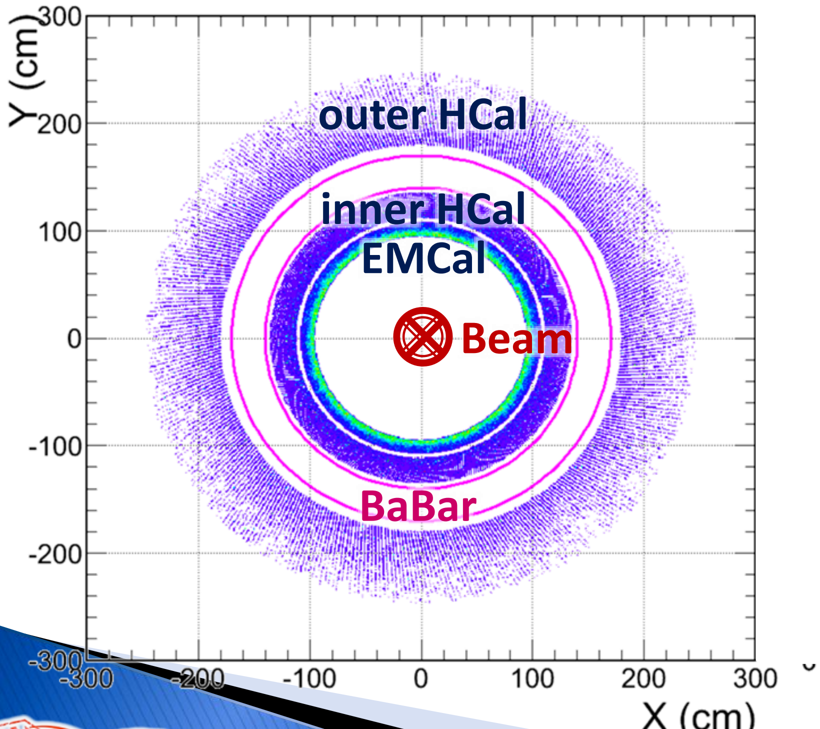


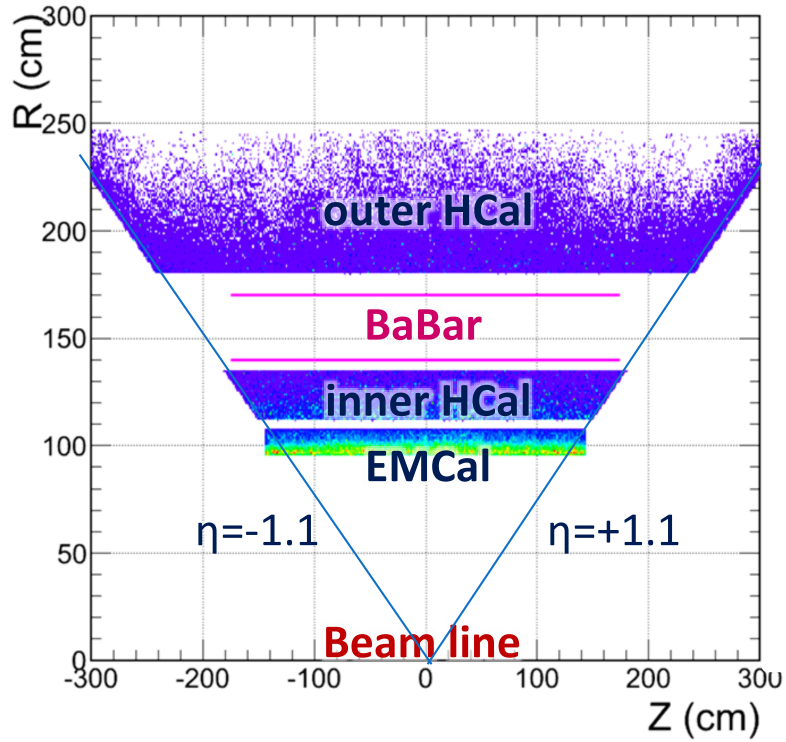
S.Stoll

sPHENIX Calorimeters

- EM calorimeter (EMCal) : 18 X_0 SPACAL
- Inner hadron calorimeter (inner HCal) : 1 λ_0 Cu-Scint. sampling
- BaBar coil and cryostat. (BaBar): 1 X_0
- Outer hadron calorimeter (outer HCal) : 4 λ_0 Steel-Scint. sampling

Calorimeter energy distribution in full event central AuAu collisions and realistic magnetic field

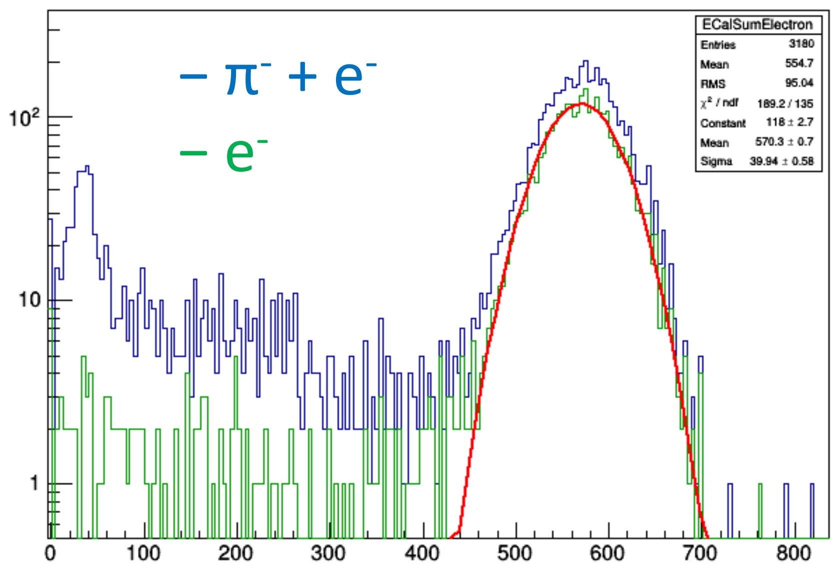




Final check should be against data

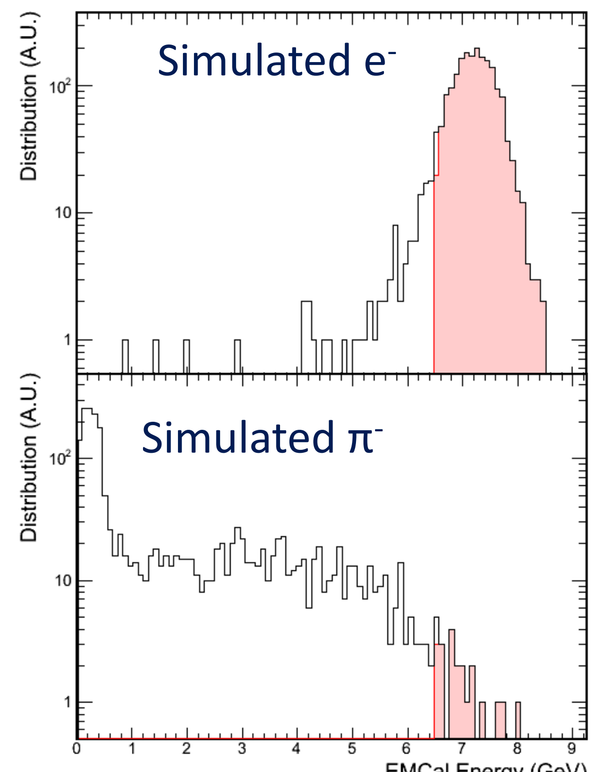
- Next steps will be quantitative check against beam test data

Courtesy : O. Tsai (UCLA)
SPACAL prototypes in 2014 Fermilab beam test
Energy sum for 5x5 towers
(asking for separated spectrum)



Sum energy in 5x5 tower (A.U.)

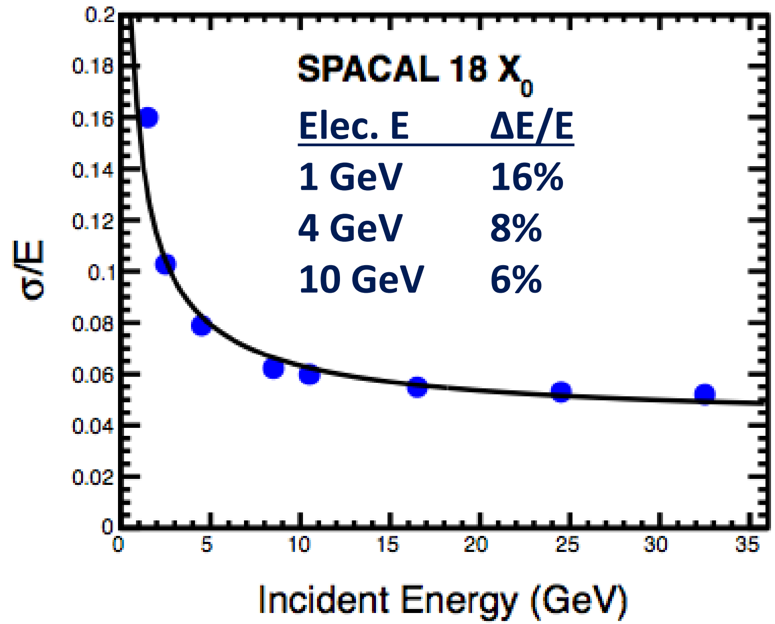
sPHENIX simulation of 8GeV e/π^-
Energy sum for 5x5 towers
(w/o scint. light modeling)



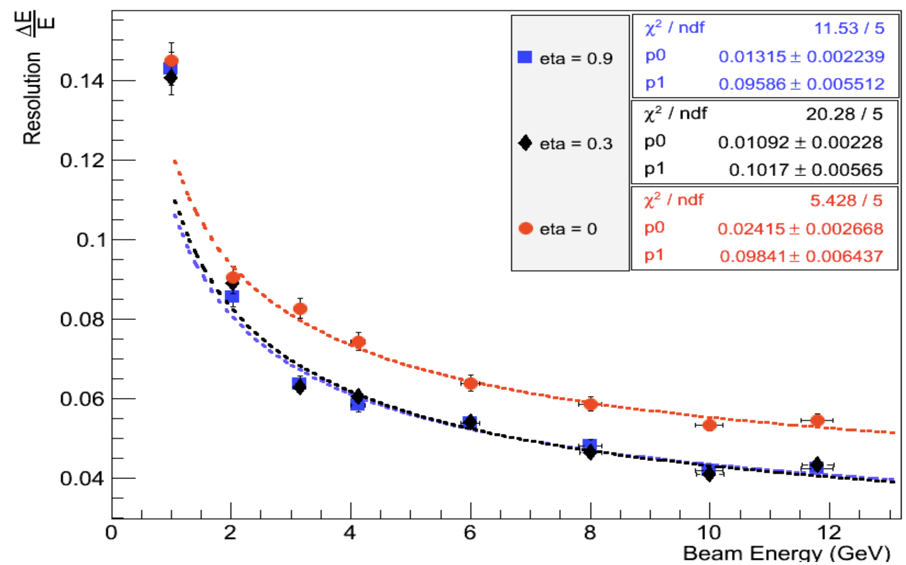
SPACAL study (1): electron resolution

- Electron resolution → Electron PID efficiency
- Compared to simulation from EIC RD1 collaboration and beam test
- Consistent in general; **more work on noise and cell structure simulation**

sPHENIX simulation
5MeV(scint.)/tower zero-suppression



EIC RD1 study
FermiLab beam tests

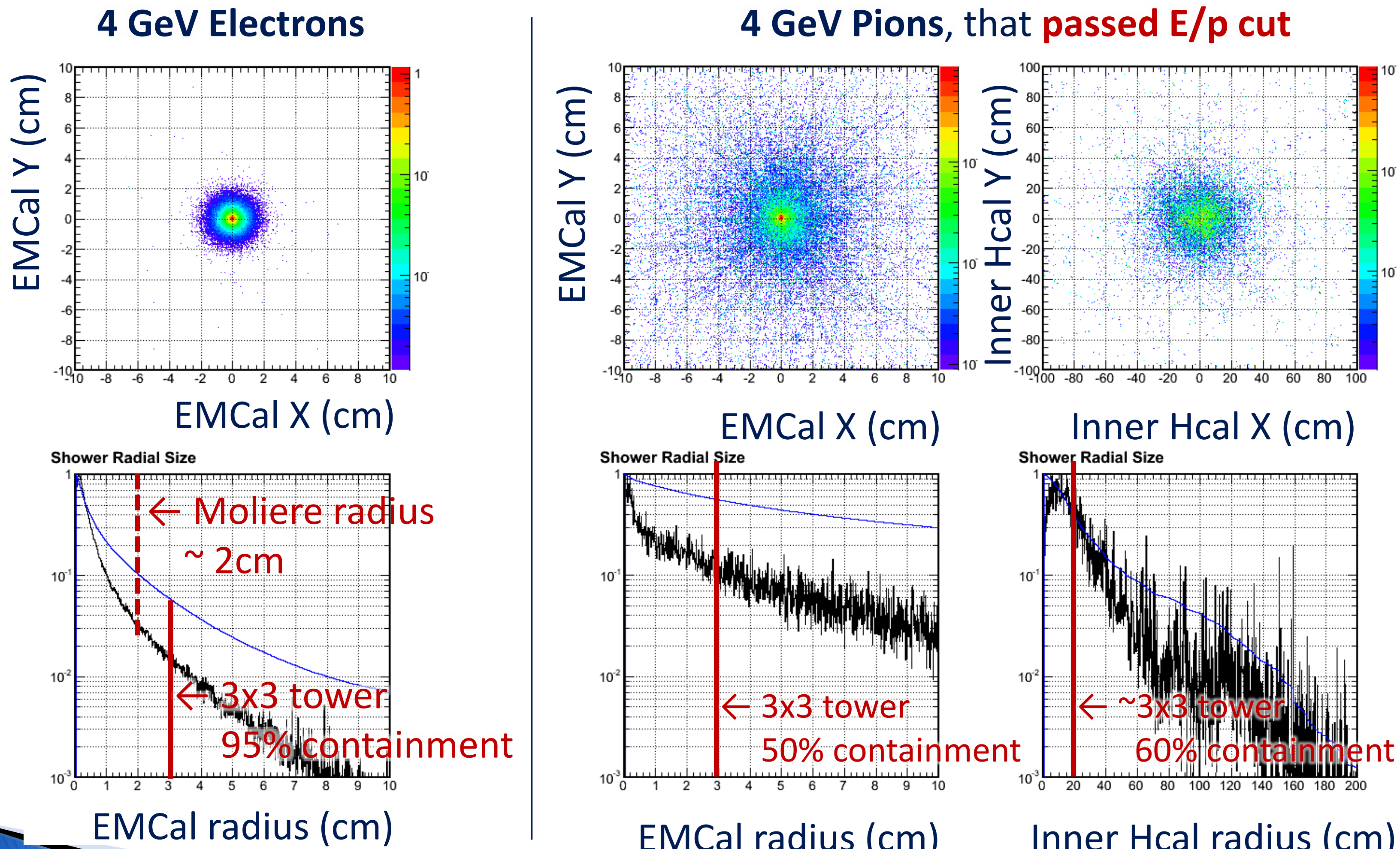


Courtesy: A.Kiselev (BNL)
DIS2014

SPACAL study (2): spatial response

- Spacial containment of showers → size of cluster

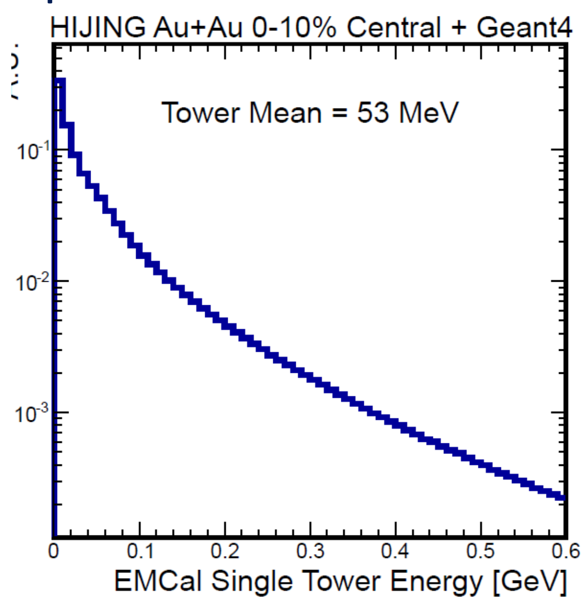
- Energy deposition (A.U.)
- Percentage outside radiu

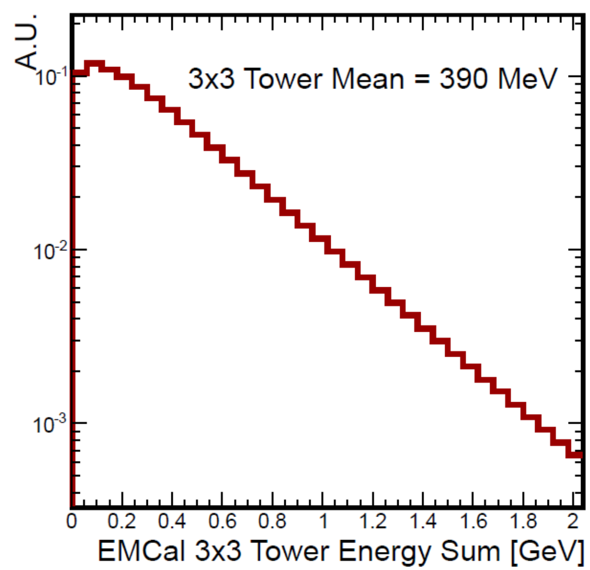


Outtie-HCal has much larger spread. See backup 1

Event background distribution in Central AuAu

- Study of electron ID in central AuAu
  1. Embed single particle simulation to full event Hijing simulations (0-4.4 fm, ~0-10% Central, in full magnetic field)
  2. Get rejection through re-optimized EMCal+ HCal cuts
- EMCal background is moderate
  - Most hadron particle leave MIP energy in EMCal
  - Tight EMCal Moliere radius
- **Inner HCal background is significant, render it less useful in electron ID** (compared with an alternative tighter E/p cut from EMCal)



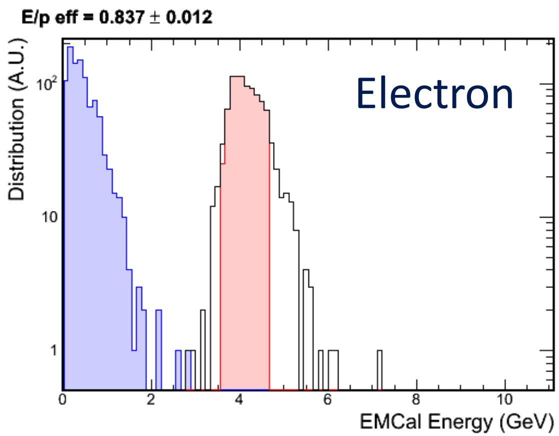


eID in central AuAu, central pseudo-rapidity

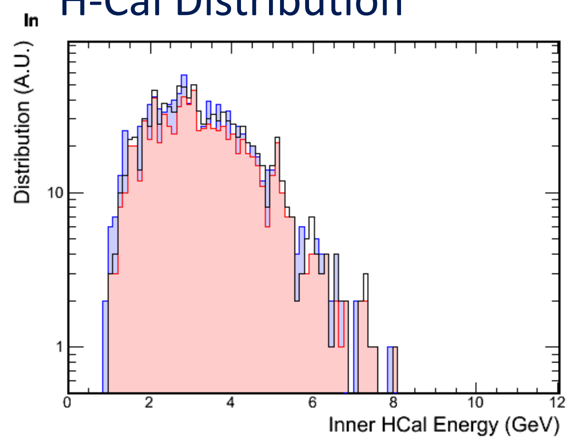
4GeV electron and pion-, |η|<0.2

EMCal tower cut : R<3cm, Hcal cut : R<20cm

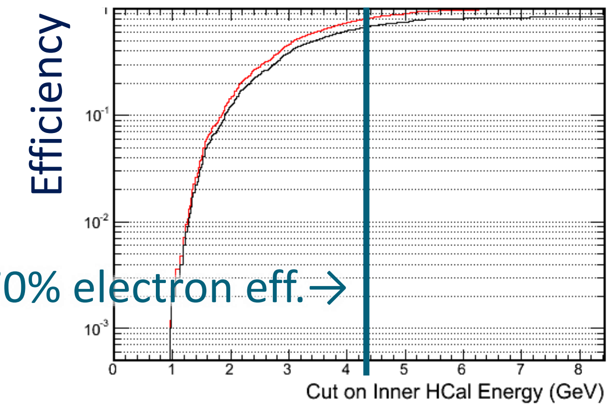
- Hijing background (AuAu 10%C in B-field)
- all c(w/ embedding)
- with EMCal E/p cut (w/ embedding)

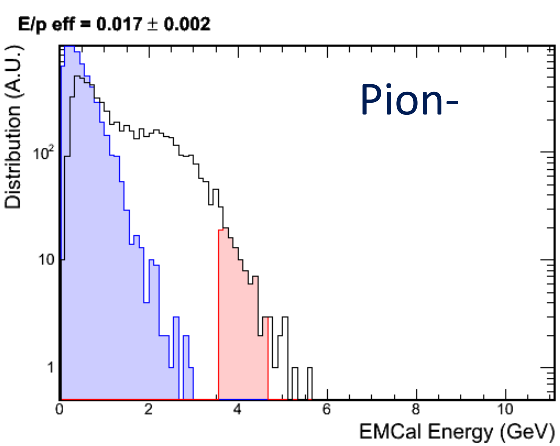


H-Cal Distribution

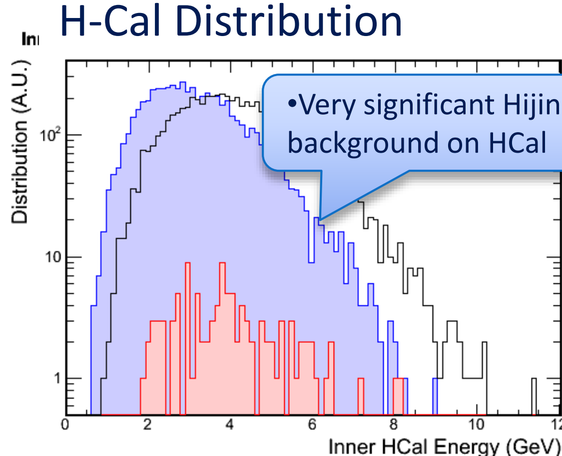


H-Cal Cut Efficiency

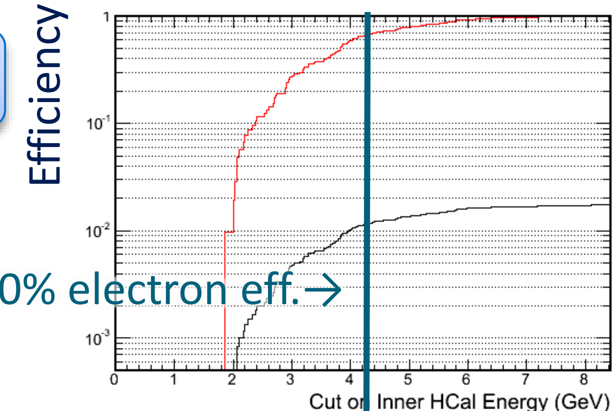




H-Cal Distribution

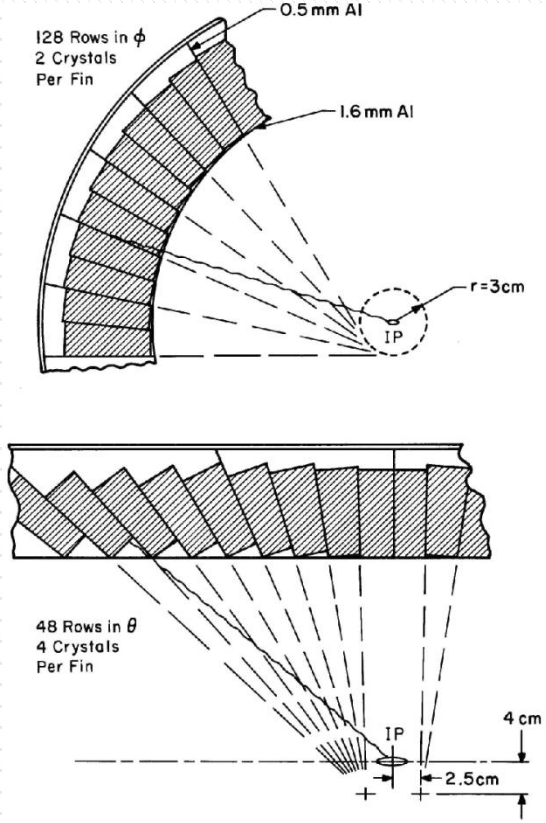


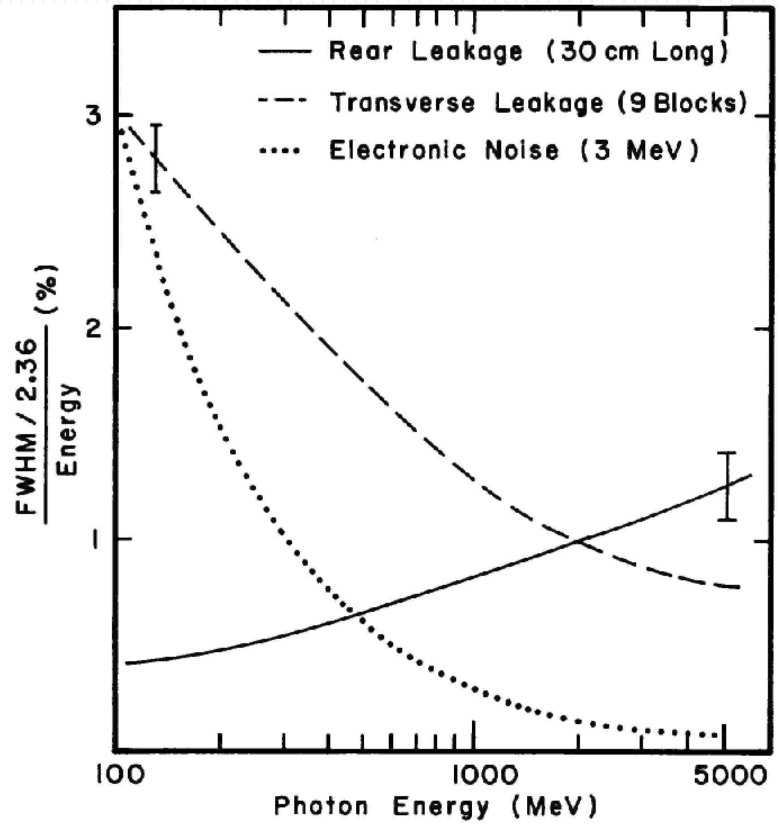
H-Cal Cut Efficiency



- Additional rejection of x2 from H-Cal
- Total rejection ~90:1

Cracks and steps are not new problem
See also projective crystal calorimeters



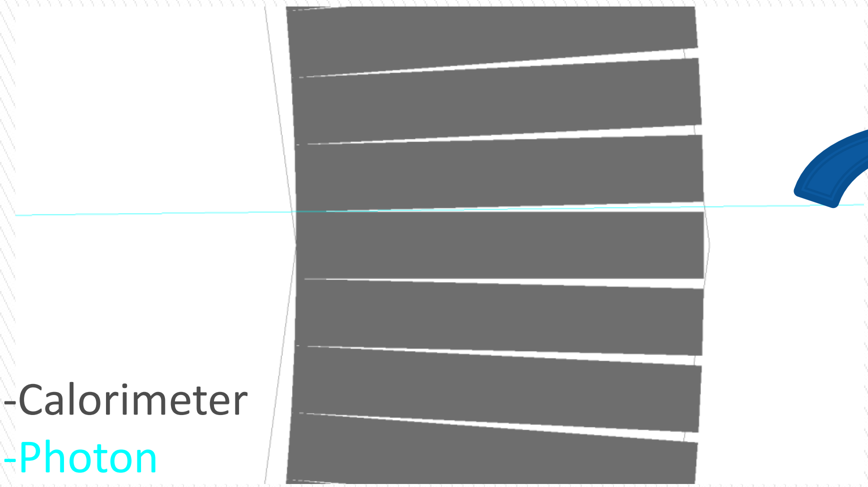


CLEO II EMCal Design

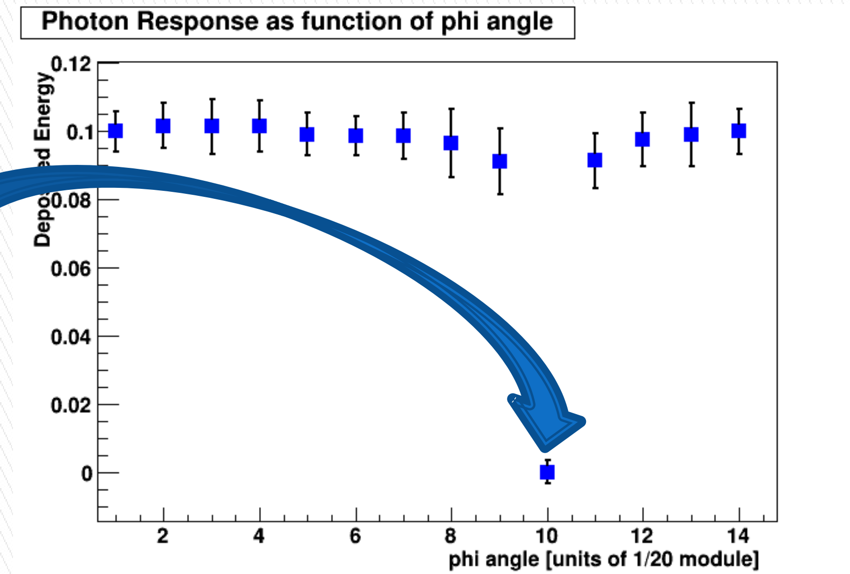
In contribution to energy resolution

Stolen from QWG3 Topical School. B Heltsley. Oct 2004

No tilt angle, no magnetic field = leakage



-Calorimeter
-Photon
-Lepton
-Hadron



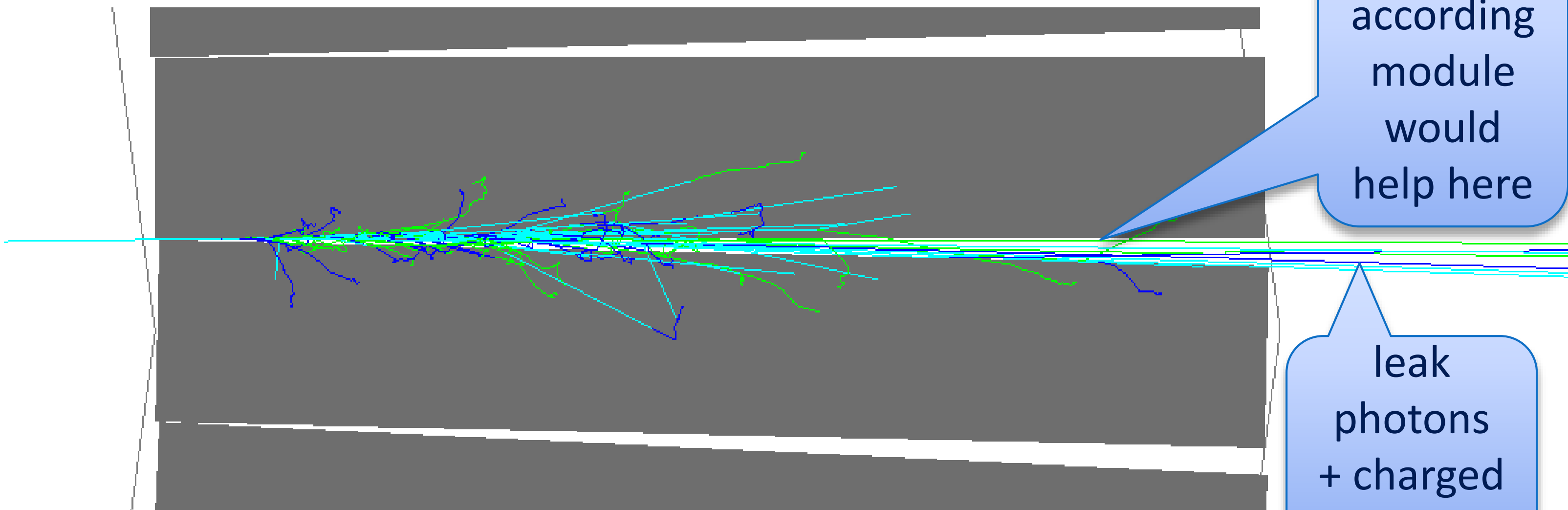
4GeV photon tunnel through the gap

Energy deposition VS hit location (from Martin P.)

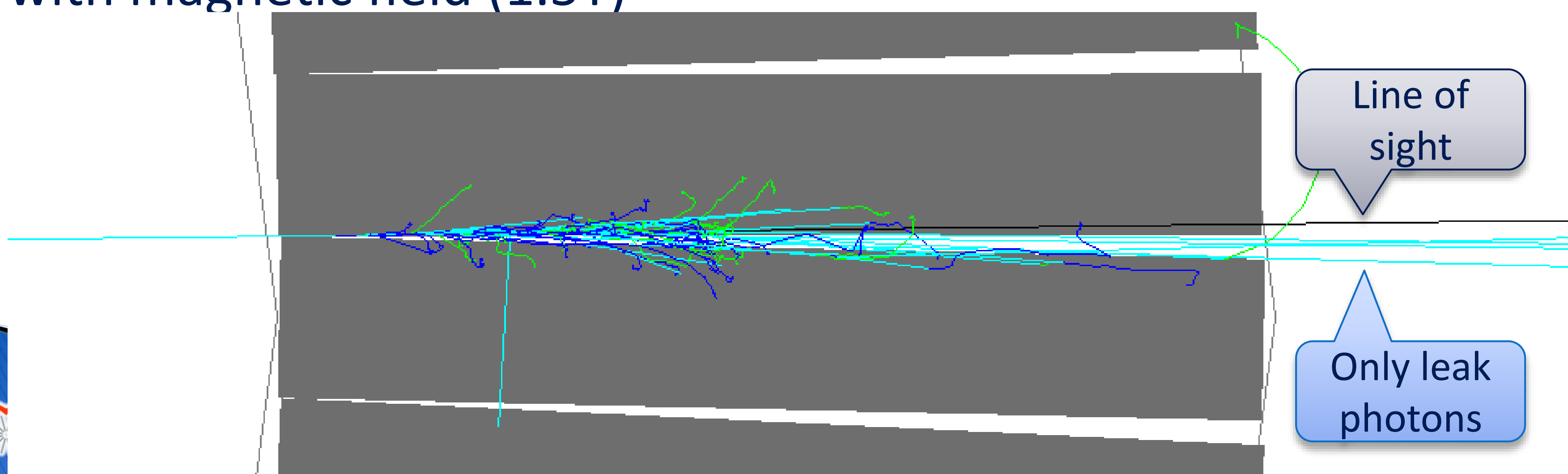
23mrad tilted blocks (no line of sight)

- With no magnetic field

-Calorimeter
-Photon
-Lepton
-Hadron
-Geantino



- with magnetic field (1.5T)

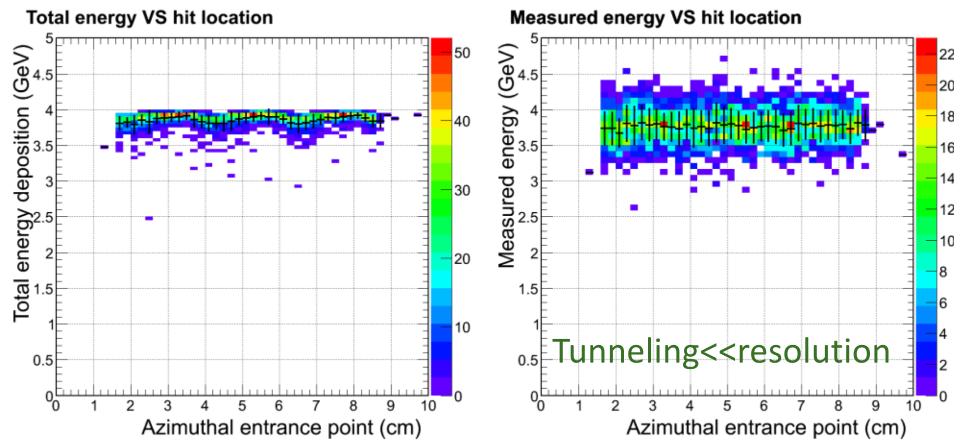


Over tilting of 196 mrad

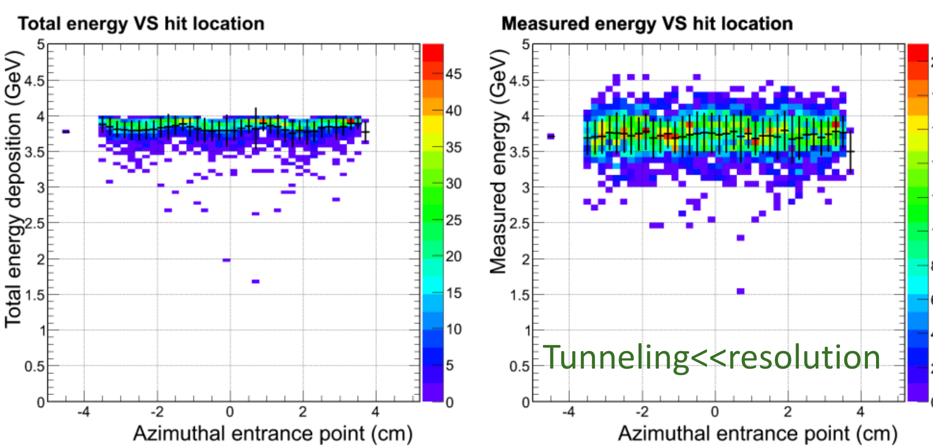
Further tilt to the block diagonal angle

- Expect to observed non-projectivitiy effect in azimuthal
- Solved the uniformity problem for Upsilon electrons
- Uniformity for other particles still need to be better understood

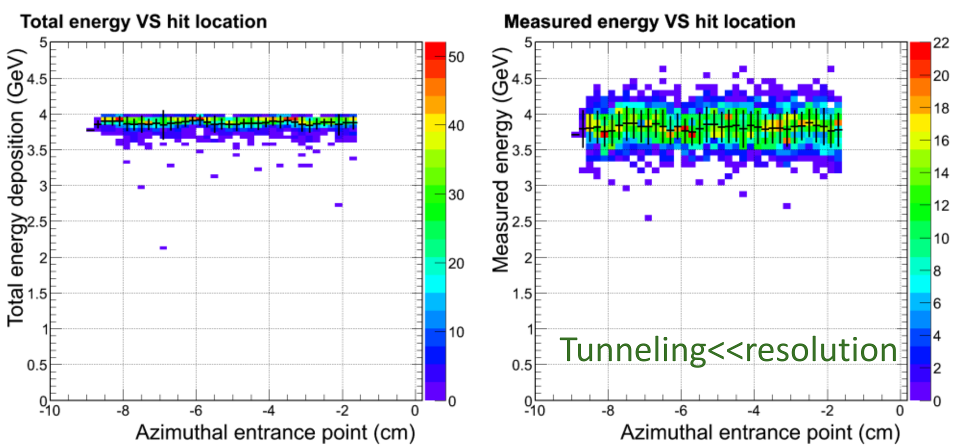
Lepton bended towards from gap



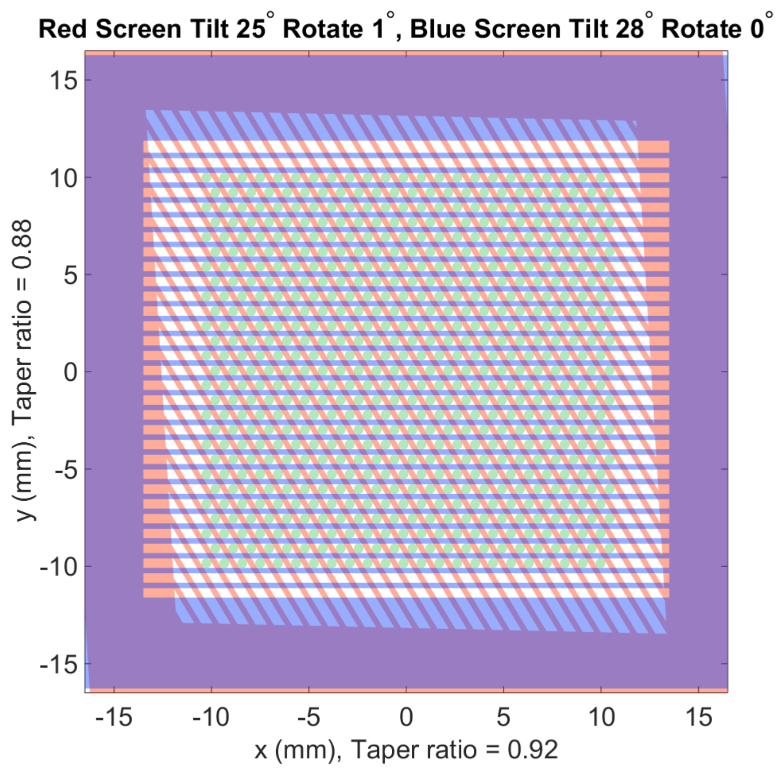
Photon

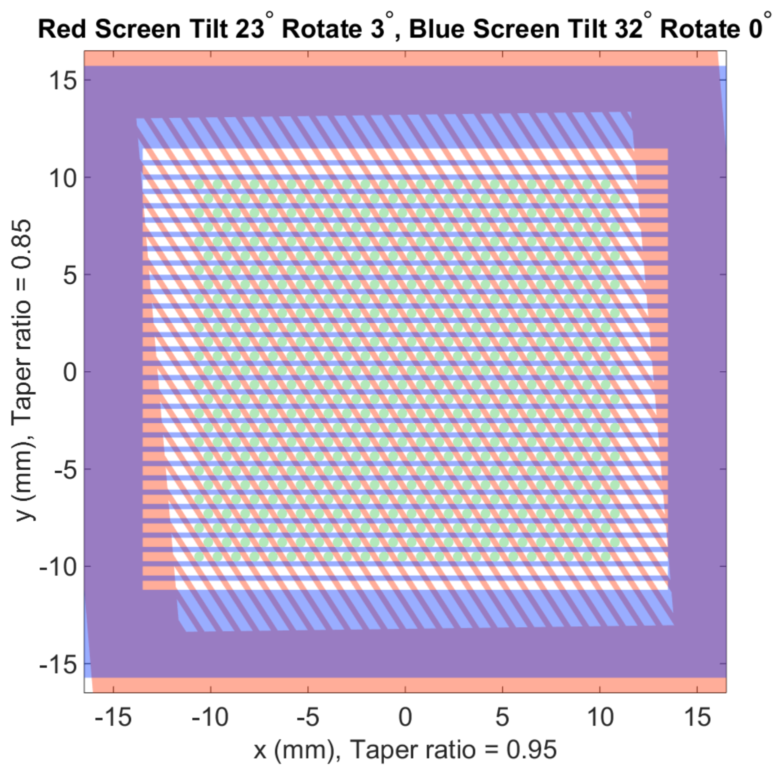


Lepton bended away from gap



Flexible taper ratio (different module for different eta rings)





92% - 88% taper

95% - 85% taper

Early SoLID Shashlyk EMCal simulation

1.5 T magnetic field along direction of EM shower